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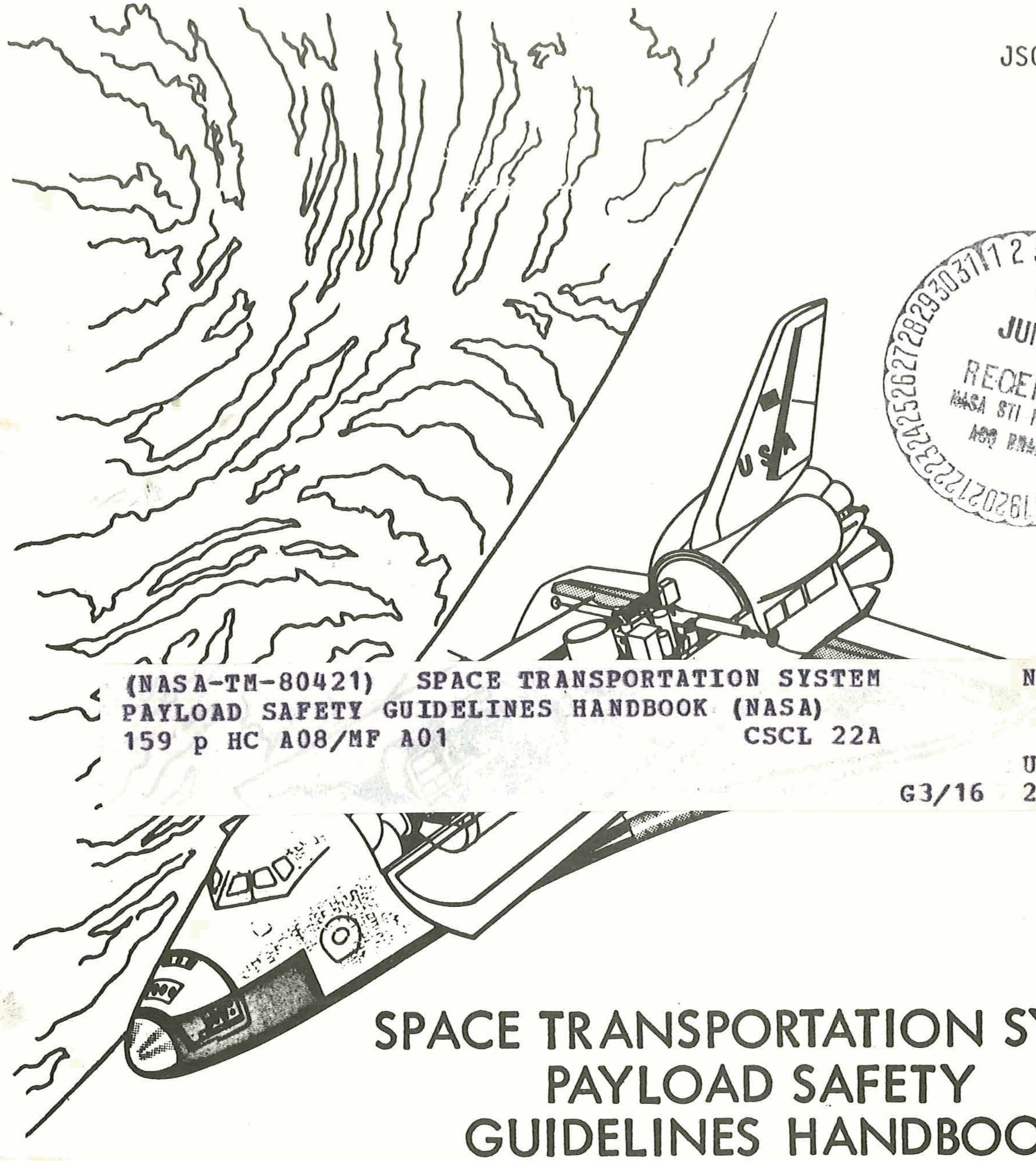

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SPACE TRANSPORTATION SYSTEM PAYLOAD SAFETY GUIDELINES HANDBOOK

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

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PREFACE

The "Payload Safety Guidelines Handbook" has been prepared to assist STS (Space Transportation System) payload developers in achieving compliance with the documented payload safety requirements of the NASA Office of Spaceflight. The guidelines contained in this handbook apply to all payloads to be carried by the STS. They are not to be construed as requirements but are suggested design or operational options for the elimination and/or control of hazards.

The guidelines incorporate system safety experience accumulated by NASA, DOD, and aerospace industry sources on manned and unmanned spacecraft and aircraft. Of necessity, the guidelines are generic because they are intended to be applicable to any payload.

This publication will be reviewed and revised as appropriate to reflect new experience or changing emphasis to ensure continuing viability. Any questions or requests for additions and changes should be directed to Mr. J. B. Hammack, Chief, Safety Division, code NS, Johnson Space Center.

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1.0 INTRODUCTION.- The STS (space transportation system) will be used to carry into space many different types of payloads. The developers of these payloads will have varied experience and familiarity with both systems safety and manned spaceflight. The payload safety guidelines handbook has been developed at the request of the OSF/Director, Reliability, Quality and Safety and the NASA Office of Planning and Program Integration to provide the payload community with a centralized source of accumulated experience achieved in past Government and industry aerospace programs. The guidelines handbook imposes no requirements on the payload community but suggests options for the elimination and/or control of hazards.

The goal of this handbook is to promote payload safety while permitting the maximum flexibility in the control of hazards. Two key elements involved in achieving this goal are (1) effective communications between NASA and the payload community and (2) utilization of the knowledge and experience from previous programs. The payloads safety guidelines handbook is intended to provide these elements to the payload community.

This handbook provides the payload developer with a uniform description and interpretation of the potential hazards which may be caused by or associated with a payload element, operation, or interface with other payloads or with the STS. It also includes guidelines describing design or operational safety measures which suggest means of alleviating a particular hazard or group of hazards, thereby improving payload safety.

1.1 PURPOSE.- The purpose of this handbook is to assist the payload developer in achieving compliance with the documented payload safety requirements of NASA OSF. The handbook accomplishes this intent by:

a. Identifying the basic hazards involved with payloads intended for the STS.

b. Providing design and operations safety guidelines which eliminate or minimize potential hazards and thereby improve payload safety.

c. Providing the safety guidelines in a subsystem format for easy access and use.

1.2 SCOPE.- The guidelines contained in this document apply to all payloads intended to be carried by the STS. They are suggested design or operational means of avoiding hazards which if not corrected could adversely affect the safety of the STS. The STS consists of the space shuttle, spacelab, upper stages and ground sites needed to support these elements.

1.3 ORGANIZATION.- This handbook is organized into three sections: Introduction, STS Payload Hazards Definition, and Payload Safety Guidelines. Section 2.0, STS Payload Hazards Definition, defines the top level hazards affecting payloads. It also covers the various causes, failure modes, and potential effects of these hazards.

Section 3.0 of the handbook contains the safety guidelines which have been prepared to assist the payload developer in improving the design and operational safety of his particular payload. The guidelines cover STS payloads located in the orbiter payload bay, inside the crew cabin, in the spacelab, or external to the orbiter.

The guidelines are not designed for specific payloads but contain generic data which will assist individual payload designers and developers. This approach is necessary because of the wide variety, complexity, and early stage of development of the majority of payloads proposed for the STS.

The guidelines address payload design, operations during flight, and operations during ground activities including transportation, test and checkout, installation, and refurbishment. For the convenience of the developer, the guidelines are grouped by commonly understood subsystem designators such as electrical, pyrotechnics, etc., and by subject titles such as materials, human factors, and radiation.

Each subsystem guideline section is preceded by an index for that subsystem. The index identifies the main elements comprising that subsystem. The top level hazards associated with each of these main elements are identified in the index and comprise a summary of those hazards applicable to that particular subsystem element. This cross index will aid the handbook user in determining which guideline satisfies his particular application.

1.4 DATA SOURCES.- The identified hazards and the safety guidelines were developed from a data base consisting of manned and unmanned spacecraft and aircraft experience from NASA, DOD, and industrial sources. Data obtained from these sources included existing safety studies and safety standards, related payload studies, and payload description documents. The documents from which these data were obtained are listed in the bibliography section for background information, since pertinent data has been incorporated into the body of this handbook. The listing of a document in the bibliography section is not to be construed as the imposition of the document as a requirement.

2.0 STS PAYLOAD HAZARDS DEFINITION.

2.1 PAYLOAD HAZARDS.- A hazard is the presence of any potential risk situation caused by an unsafe act or condition. There are numerous potential risk situations associated with the STS payloads which directly or indirectly affect the safety of STS flight or ground personnel. One of the purposes of this handbook is to assist the payload developer in recognizing the hazards associated with STS payloads. The identification of such hazards is the necessary starting point for the development of safety guidelines which may be used to eliminate or control the hazards.

Although there may be many secondary or contributory hazards, 10 basic hazard groups were identified as the primary concerns applicable to STS payloads. These hazards have safety implications during all mission phases on ground and flight crews, the STS vehicle, or other payloads.

The hazard groups were derived from a variety of sources such as: (a) a general knowledge of STS payload energy sources which are primary sources of hazards, (b) utilization of experience gained from previous manned space programs as to hazards encountered or prevented, and (c) other representative sources of hazard grouping or categorizations. The list of hazard groups used in this handbook is in general agreement with all such sources. A difficulty common to all lists, including this one, is that there is considerable overlap between hazard groups, and the assignment of any secondary hazard to a particular group can often be arbitrary. The manner in which hazards are grouped or subdivided is therefore not particularly significant. What is important is that the payload developer be aware of all the basic hazards associated with his payload.

2.1.1 Hazard Description.- The basic hazard groups, including representative examples of their causes and effects, are discussed briefly in the following paragraphs. The groups are numbered consecutively from 1 to 10 to agree with the hazard references in each subsystem guidelines index.

1. COLLISION.- This group involves those hazards which occur when payloads or payload elements are allowed to break loose and impact STS structure, other payloads, or flight and ground personnel. These hazards are caused by structural failure, procedural error or inadequate ground handling equipment. Failure of payload attach points can create equipment projectiles that can penetrate manned compartments and injure the crew. Penetration of the cabin may result in loss of cabin pressure and crew asphyxiation. Inadequate or incorrect procedures during payload deployment, retrieval, or during EVA (extravehicular activity) can lead to collision of the payload with the orbiter or other STS elements. Damage to critical orbiter control surfaces or primary structure is possible and could prevent a successful return to Earth. Ground handling equipment such as slings, cradles, holddown arms, etc., can fail and injure personnel during ground operations.

2. CONTAMINATION.- This group of hazards is associated with the release of toxic, flammable, corrosive, condensible, or particulate matter. Contamination is caused by leakage, spillage, outgassing, loose objects, abrasion, and from the growth of fungus or release of volatile condensible materials. Leakage of hazardous fluids or gases can be initiated from cracked or worn seals, gaskets, valve seats, flanges and joints. Spillage of liquids from containers, tanks or valves can directly, or indirectly by vaporization, degrade the atmosphere or equipment operation. Many materials outgas toxic products, irritants, or foul odors which can damage the senses, and the respiratory system of crewmen. Loose objects, dirt, and abrasive action within payload components can provide a source of particles that float in the zerogravity environment of habitable areas and can enter into the eyes, ears, noses, or mouths of personnel and into sensitive equipment. Fungi growing from materials providing nutrients in moist, warm environments are bacterial infection sources and contaminants in operating equipment.

3. CORROSION.- This group involves those hazards resulting from the structural degradation of metallic and nonmetallic equipment. Material corrosion can be caused by a variety of means. Leakage of corrosive or reactive material onto metallic or nonmetallic equipment can quickly degrade its usefulness. Material incompatibility or the joining of certain dissimilar metals can lead to corrosion. Environmental extremes of temperature and humidity are sources of deterioration of metals containing carbon or for most organic materials. Examples of the types of corrosive processes which can degrade metal and nonmetal equipment include stress corrosion, electrolytic corrosion, and polymerization. Causative agents will include acids, salts, solvents, halogens, etc. The effect of corrosion on equipment can lead to mechanical failures, premature wear, seizure, and short circuits. The loss of a critical function due to corrosion could lead to any of the 10 basic hazard groups identified herein, and the loss of crew, vehicle, or mission is possible.

4. ELECTRICAL SHOCK.- This group includes those hazards responsible for personnel injury or fatality because of electrical current passing through any portion of the body. Electrical shock can be caused by contact with a "live" circuit because of human error in performing an operation, a procedural error, or an equipment failure such as an insulation breakdown in exposed wiring. Other causes may be static electricity discharge, lightning strikes, or short circuits caused by moisture, bent connector pins, or wires, etc. Static electricity or lightning could be hazardous without adequate grounding or shielding protection. The effect of electrical shock can vary from a mild burn to loss of consciousness and electrocution. Cuts and bruises are possible from the involuntary reaction to the shock.

Other electrical system hazards affect the performance and operation of equipment and thereby affect the crew indirectly. Almost all payload subsystems are either electrically controlled or contain electrical components which can malfunction and cause almost any conceivable hazardous situation depending on the time and location of occurrence. For example, electrical arcing could result in fire or a faulty electrical circuit relay could cause premature activation of a pyrotechnic device. Electrical equipment malfunctions should therefore be considered as contributing factors for each of the 10 basic hazard groups.

5. EXPLOSION.- These hazards result from the the violent release of energy as a result of payload element overpressurization, fire, chemical reaction, excessive temperature, malfunctioning equipment or structural failure causing the release and collision of equipment with other structures or equipment. The overpressurization of pressure vessels, accumulators, batteries, etc., can result in explosion. Excessive temperature from a fire or a failed cooling system can result in explosion of cryogenic tanks, gas generators, pyrotechnic charges, squibs, etc. Equipment which can disintegrate explosively include pumps, motors, blowers, rocket motors, generators, lasers, etc. The effects of these explosive hazards on the crew could range from fragmentation injuries to eye or respiratory system irritation, burns, and asphyxiation. These effects would be the result of shrapnel or toxic/corrosive fluids or gases being released from the exploding component.

6. FIRE.- This group deals with the rapid oxidation of payload element combustibles. Fire can occur when a fuel and an oxidizer are exposed to an ignition source. It can also occur when hypergolics are inadvertently mixed. Fuels or combustibles consist generally of organic material, chemicals, and certain metals. Examples of these materials include rubber, wood, clothing, paint, plastics, solvents, and magnesium. Any high temperature device or source of electrical arcing or sparking can provide the ignition source for fire. Examples of these devices are bearings, motors, generators, heaters, lasers and faulty electrical wiring. The effects of fire can be catastrophic in the closed environment of a space vehicle. Death by asphyxiation, smoke inhalation, or burns are directly attributable to fire. The destruction of critical controls or life support equipment by fire can indirectly cause the loss of crewmen or the vehicle.

7. INJURY AND ILLNESS.- This group includes those hazards capable of inflicting physical injuries or illness of any sort on the flight or ground crews during all mission phases. Physical injuries may be caused by impact or collision with stationary objects having sharp edges or protruding parts or with shrapnel or projectiles from exploded tanks or accelerated loose objects. Physical injuries may also be caused by ingesting particulate matter, touching hot or cold surfaces, and by the loss of breathable atmosphere. Crew illness could result from exposure to pathogenic bacteria, toxic materials, or to excessive radiation levels.

8. LOSS OF ORBITER ENTRY CAPABILITY.- This group involves those hazards which could degrade the structural, aerodynamic, and thermodynamic integrity of the orbiter and could prevent its safe return from orbit. Such orbiter functional degradation can be caused by payload elements which cannot be retracted within the orbiter mold line or which prevent the closure of the payload bay doors. It can also be caused by payload element contact or collision with orbiter structural members, control surfaces, or primary insulation areas during payload deploy/retrieval activities. The payload elements preventing payload bay door closure include booms, antennas, solar panels, and other hinged or extendable/retractable components. Failure of such equipment may be caused by loss of electrical or hydraulic power, structural fracture, and jammed or malfunctioning retract mechanisms. Pressure vessel rupture, inadvertent firing of pyrotechnics or activation of propulsion systems could result in collision with sensitive areas of the orbiter. The eventual consequence of these hazards could be abandonment of the orbiter in space or possible loss of the crew and vehicle during an attempted entry.

9. RADIATION.- This group involves those hazards associated with the exposure of the human body and sensitive control equipment to ionizing radiation, ultraviolet or infrared light, lasers, and electromagnetic or RF (radio frequency) generating equipment. Ionizing radiation hazards may be caused by leaking or inadequately shielded radioactive equipment such as RTG's (radioisotope thermoelectric generators), particle accelerators, vidicons, liquid metal heat exchangers, etc. Overexposure of personnel to such radiation could result in tissue damage, permanent injury, or death. The crew could experience painful burns and eye damage from overexposure to ultraviolet or infrared light sources or to concentrated laser light beams. RF and electromagnetic radiation sources such as radar equipment and antennas can trigger ordnance devices or interfere with operation of critical communication equipment.

10. TEMPERATURE EXTREMES.- This group includes those hazards associated with the departure of temperature from normal. It also includes extreme heat or cold such as that generated by fire, cryogenics, and the environment of space. These hazards may be caused by insulation breakdown, short circuits, seal leaks, plumbing failures, and procedural and human error in handling or operating hot and cold generating equipment. Examples of equipment affected by temperature extremes include bearings, motors, electrical components, heaters, batteries, tanks, and lines. In addition to fire, these hazards can lead to structural degradation and mechanical equipment seizure. The ground and flight crews could suffer skin burns or frostbite as a direct result of contacting hot or cold materials. They could also be exposed to contamination hazards if overexpansion or retraction of payload components leads to the release of toxic matter.

3.0 PAYLOAD SAFETY GUIDELINES.- The payload safety guidelines in this section were prepared to assist payload developers in achieving compliance with documented safety requirements for payloads using the space transportation system. For easy access by payload developers, the guidelines are grouped into 15 generic subsystems. They provide the means for payload developers to recognize hazards and also serve as development and design aids in meeting payload safety requirements. The guidelines are a source of experience retention data for safe design and operations with a baseline of accumulated experience in manned and unmanned spaceflight as well as military and commercial operations.

Since payloads will be designed to incorporate operational safety features, most of the guidelines are design oriented. The number of generic operational guidelines included in the handbook is minimal because operations planning requires specific equipment configuration and definite mission objectives. Only the most general type of operational guidelines could be prepared and included at this early stage of payload definition. As payload equipment configuration and mission objectives are established, specific operational safety guidelines can be developed by the responsible NASA Center or by the payload developer to complement those included in the handbook.

The preparation of the payload safety guidelines consisted of four steps. (1) A data search was performed by visiting the participating NASA Centers, DOD, and the aerospace industry. (The reference sources are tabulated in the reference section of this document.) (2) The data were reviewed, and applicable safety concerns and equipment hazards were collected and categorized under the appropriate subsystems. Data were also categorized under the 10 hazards discussed in paragraph 2.1. (3) A preliminary hazard analysis was performed for each subsystem to assure that the necessary guidelines were developed for payloads. (4) The guidelines were revised for payload applicability and developer understanding .

Each of the 15 subsystem guideline subsections contains an index, a subsystem description, and the guidelines. The subsystem description contains a description of the hardware elements and their interfaces with a brief discussion of the associated hazards. The guidelines contain three main headings: design, flight operations, and ground operations. Under these three headings will be found subheadings of equipment elements. Included with the subheadings are the hazards (as defined in paragraph 2.1) which are to be controlled by the guidelines.

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BIOMEDICAL GUIDELINES

3.1 BIOMEDICAL

System Description.- The biomedical subsystem consists of medical experiment equipment designed to obtain data on man's adaptation and performance in the space environment. It also consists of scientific equipment designed to obtain experimental data on the effects of space environments on micro-organisms, plant life, primates, vertebrates, and invertebrates.

The medical experiments consist of measuring instruments such as ergometers, probes, body mass measuring devices, and blood pressure measuring devices. Also included are recording instruments such as electroencephalographs, electrocardiographs, metabolic analyzers, and the associated electronic assemblies. Many of these types of equipment have been developed for manned space programs and will continue to be required and refined for future applications.

The equipment for scientific investigation of living cells will range in complexity and design dependent on the scientific objectives. A small part of this type of equipment was designed for the Skylab Program. The study of primates as part of manned spaceflight will be accomplished for the first time during the Space Shuttle Program. The study of lower animals and plants, many for the first time, will also be performed on the shuttle.

Basic life support systems, including feeding and waste management systems, will be required in addition to measuring and recording equipment, probes, surgical tools, specimen containers, refrigeration equipment, and incubators for bacterial studies.

Associated Hazards.- The hazards associated with the biomedical subsystem are contamination, electrical shock, explosion, fire, illness, and injury. Contamination hazards can be generated by uncontained waste matter from biological experiments. Uncontained waste matter can enter into equipment, become part of the breathable atmosphere, or can generate bacteria harmful to the crew. Where possible, electrical shock hazards should be identified and eliminated from medical equipment by design. Life support systems containers designed for animals and plants should have emergency vent systems to avoid overpressurizations leading to explosive hazards. Flammable fluids used in experiments should be contained and should not be allowed to escape into the habitable areas. It is suggested that experiments containing pathogens should provide a redundant means of containment.

The following guidelines are concerned with experiments involving humans, animals, and biological specimens. Section 3.4, ELECTRICAL, should be reviewed for additional guidelines applicable to medical experiments.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.1 SUBSYSTEM BIOMEDICAL

ASSOCIATED HAZARD	GUIDELINES
	3.1.1 Design
	3.1.1.1 Medical Experiments
Electrical Shock	a. Medical equipment to accomplish or support a crewman biological test in which electrical power is used should be designed with redundant electrical shock protection circuits which remove the input power to the equipment when a leakage current level of 100 microamperes is sensed.
Electrical Shock	b. Medical experiments such as the ergometer which utilizes a vectorcardiogram should be designed with electrically insulated restraints, shoes, seat, and handlebars to prevent parallel electrical paths.
Fire, Contamination, Illness, Injury	c. The design should specify that medical equipment used at the entrance or within a body opening of a crewman should be sterilized and individually packaged. Disposal facilities should be provided to contain used packaging materials and medical equipment to prevent accumulated trash which can create hazardous conditions of fire, contamination, and crew injuries.
Fire	d. Medical experiments which use flammable fluids, such as methane or alcohol, should be designed to prevent the fluids from creating a hazard.
Illness, Contamination	e. Experiments supplying gases to be inhaled by a crewman should include a contamination filter. Location of the filter should provide maximum protection of the subject with minimum impact to experiment results. The gas should be positively identified and tested prior to mission operation. Cleanliness levels of the gas should be maintained during servicing, and visual placards should be installed on containers describing contents and use.
Illness	f. Rotational medical equipment such as a rotating chair, requiring crewman participation, should be designed with a braking device for quick stopping to release the crewman under emergency conditions such as crew emergency egress.
Illness, Injury	g. Equipment to accomplish medical experiments which encapsulate a crewman or use multiple straps should be designed for quick release by the crewman under emergency egress (i.e., single release point). Devices which enclose a crewman and apply either positive or negative pressure should be designed for quick depressurization or repressurization to allow the crewman a rapid egress under emergency conditions.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.1 SUBSYSTEM BIOMEDICAL

ASSOCIATED HAZARD	GUIDELINES
	3.1.1.2 Microbiology
Contamination, Illness	a. Experiments containing disease-producing bacteria and pathogens should be hermetically sealed and packaged in containers or compartments to isolate these experiments. Human contact with pathogens should be prevented during preflight preparation, flight operations, and postflight to preclude contamination of ground and flight crews. The payload contractor should develop and provide detailed procedures for handling, operating, storing, and disposing of microbiological experiments.
Contamination, Illness	b. Microbiological experiments requiring pressurized atmosphere should be designed with a self-contained system and should be completely isolated from the crew environmental control system to prevent contamination. The design of the enclosure should allow for a lower internal pressure than the ambient.
Contamination, Illness	c. The packaging of hazardous micro-organism containers should be designed to withstand abort and crashlanding forces to protect the crew, ground personnel, and the general population from contamination.
Contamination, Illness	d. When biological organisms are to be used in experiments during on-orbit operations, bacteria agent control should be considered as part of the experiment design. The controls should be placed with the experiment organisms within the incubator. The bacteria agent control container should be designed to melt in overtemperature conditions, thereby releasing the controlling agents to destroy the biological organisms. Biological disinfectants such as Isopropyl alcohol, Phisohex, and Zyphrin chloride should be available for cleaning small spills.
	3.1.1.3 Biological Life Support Systems
Contamination, Illness	a. The design of biological experiments using plants, animals, or other live organisms should consider the provision of containment, venting, or elimination of odors generated by waste products. These provisions may be in addition to those of the crew environmental control system and should be designed to assure that the crew is protected from contamination by waste products.
Contamination	b. The design of the biological support system for primates, vertebrates, etc., should provide for feeding and waste removal features to prevent contamination of the spacecraft environment. Operations with uncaged animals should be performed in a manner which does not create a crew hazard or potential danger to the spacecraft and systems.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.1 SUBSYSTEM BIOMEDICAL

ASSOCIATED HAZARD	GUIDELINES
Contamination, Explosion	c. When biological subjects, such as animals, are to be used in biomedical experiments, the design of the holding units (cages) should assure that the crew and spacecraft systems are protected from contamination. The holding unit environmental control system design should assure that the crew is protected from contamination. Controlled emergency venting should be provided for a malfunction contingency of the pressure regulator leading to a buildup of excessive pressures.
Contamination, Illness	d. When designing biological experiments, provisions for preserving and storing dead specimens, plants, etc., should be considered to prevent contamination.
	3.1.2 Flight Operations
	None.
	3.1.3 Ground Operations
Contamination, Illness	In designing experimental hardware for biological experiments, complete handling procedures should be provided. The biological experiment should be tested under the same timeline and conditions expected during flight operations to uncover any hidden hazardous conditions.

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CAUTION AND WARNING GUIDELINES

3.2 CAUTION AND WARNING (HAZARD DETECTION AND SAFING)

System Description.- The caution and warning system is the means used to monitor parameters of flight equipment functions that have the potential of endangering flight or ground crews. Caution, warning, and emergency data signals from a payload to the orbiter could be useful when a specific payload hazard is identified and has a reasonable probability of occurrence, and the crew is able to take corrective or protective action. The system will consist of sensors to measure malfunctions or out-of-limit conditions, a power source and data transmission system, and a visual and audible signal in the orbiter cabin to alert the crew to an actual or impending hazardous situation. During launch or ground operations, caution and warning signals may also be displayed by the GSE (ground support equipment). Backup measurements and displays may be required for the crew to diagnose or interpret the caution and warning signals.

The caution and warning system will transmit emergency, warning, and caution type data. Those classifications are defined as follows:

Emergency.- That condition or situation which creates an immediate crew hazard and which requires immediate, instinctive crew action. An example on other programs has been fire or rapid loss of cabin pressure.

Warning.- That hazardous condition which in and of itself can cause loss of vehicle or crew and which requires crew action. An example could be premature arming of solar panel deploy mechanisms.

Caution.- That hazardous condition which, in combination with other system failures, may cause loss of vehicle or crew if uncorrected.

The payload developer (subject to review and concurrence by the STS operator) will determine when it is not feasible to eliminate a hazard by design. He will also be responsible for that portion of the caution and warning system on the payload side of the interface. This will generally consist of the sensing or detecting devices used to measure safety critical parameters, the electrical circuitry for powering the measuring devices, and the circuitry for carrying the resulting signals to the STS interface. The payload developer may also have responsibility for furnishing the controls for safing the payloads and command overrides for safety critical functions.

Associated Hazards.- Design is the most desirable method to eliminate or reduce hazards to acceptable levels. Where this is not possible, the next best measure is to provide the crew with a caution or warning to which a crew response is necessary if an out-of-tolerance condition exists or if a failure is imminent. Caution and warning systems of this type have been provided on previous manned space programs for use when immediate action is needed to correct a hazardous situation, to actuate emergency backup systems, or to permit escape from the vehicle.

The guidelines listed in this section are suggested methods of assuring that the crew has adequate information to react to potentially hazardous situations. The guidelines, however, are not to be taken as NASA requirements.

Safety critical conditions or potentially dangerous situations include the following examples: (1) fire, smoke, or high temperature sources signaling impending fire; (2) overpressurization of pressure vessels signaling impending explosion or rupture; (3) the presence of toxic, corrosive, or explosive vapors; (4) leakage of radioactive materials; and (5) critical electric distribution points for detecting over or under voltage and current. The choice of a detector (measurement device) is primarily dependent on its ability to produce accurate and reliable information regarding real hazardous conditions with no false indications under any environmental conditions.

The caution and warning guidelines contained in this section are limited to those which are the responsibility of the payload developer. It should be pointed out that there are numerous other design safety criteria for caution and warning elements and operations which are the responsibility of the STS operator. Because of this dual responsibility and the critical nature of this subsystem in protecting the crew and flight hardware, joint decisions will be required to determine type and quantity of parameters to be monitored and transmitted and the safety controls and override provisions necessary for particular payloads.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.2 SUBSYSTEM CAUTION AND WARNING

ASSOCIATED HAZARD	GUIDELINES
	3.2.1 Design
	3.2.1.1 <u>C&W (Caution and Warning) Elements</u>
All	a. The generation of erroneous signals should be minimized to protect the crew from irritation and eventual lack of confidence in safety critical data.
All	b. An inhibiting function capability should be provided in each sensor circuit to isolate a single malfunctioning sensor and permit normal operation of all other sensing units.
All	c. Emergency controls used for shutdown, safing, alarm, or corrective action should be clearly marked, visible, and readily accessible to operating personnel.
	3.2.1.2 <u>C&W Parameters</u>
All	a. Typical candidates for C&W parameters are itemized as follows. The list is not complete because there is no universal list of C&W parameters for all payloads. It may, however, be of assistance to a payload developer who may have to consider the inclusion of C&W as part of his payload development.
	(1) Atmospheric contamination - to detect leakage, spillage, or release of toxic gases, fluids, or particulate matter.
	(2) Overpressurization of pressure vessels - to detect potential rupture or explosion where practical by measurements of pressure, temperature, strain, or other means.
	(3) Thermal overheat - where potential overtemperature conditions and safe limits are exceeded in safety critical heaters, bearings, thermal insulation, thermal controls, etc.
	(4) Radioactive or electromagnetic radiation leakage.
	(5) Other potentially hazardous elements or conditions which may be harmful to the crew and are possible candidates for C&W parameters include: (a) critical electrical system over and under voltages and currents, and (b) inadvertent or incorrect operation of a laser system.
	3.2.2 Flight Operations
All	The C&W system should be active during those periods when the hazard potential exists and the flight crew is in close proximity to the payload.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.2 SUBSYSTEM CAUTION AND WARNING

ASSOCIATED HAZARD	GUIDELINES
	3.2.3 Ground Operations
All	a. During ground operations, provisions should be made to allow end-to-end checks of the C&W system's functional paths. If possible, the checkout capability should include sensor function, range, and sensitivity.
All	b. The payload portion of the C&W system should be active during hazardous ground checkout involving personnel in the vicinity of the payload or STS.

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CRYOGENICS GUIDELINES

3.3 CRYOGENICS

System Description.- The technology of cryogenics concerns itself with the processes and phenomena in the temperature region below -100°C (-150°F). Within this definition, there are 12 gases that liquefy in this temperature region; namely, oxygen, fluorine, nitrogen, argon, helium, krypton, xenon, neon, methane, ethylene, ethane, and hydrogen.

Cryogens may be required in the operation of various payload subsystems. They can be used as propellants in propulsion systems or attitude control systems, as reactants in fuel cells, and as pressurants and coolants in various applications for payload systems and experiments.

System elements associated with the safe containment, delivery, and control of cryogens and that require special design and procedural considerations include pumps, storage vessels, transfer lines, seals, vent valves, relief valves, quick disconnects, and insulation. Important design considerations include materials compatibility, dimensional contraction, impact sensitivity, condensation accumulation, cleanliness requirements, purge procedures, disposal constraints, and chilldown techniques.

Associated Hazards.- The potential hazards affecting the design, handling, and operations of cryogenics systems may be divided into four general categories. These categories are:

1. Personnel exposure to extreme cold or to toxic or inert gases.- Liquid or low temperature gas will produce effects on the skin similar to a burn. This will vary with temperature and exposure time, but the eyes can be damaged by very brief exposure to cold gases. Prolonged inhalation of cold gas, whether respirable or not, can produce serious lung disorders. Most liquefied gases have low toxicity, but adequate ventilation is essential because a small amount of liquid can rapidly convert to a large volume of gas depleting the normal oxygen content and can create a breathing hazard. In sudden asphyxia, such as from inhalation of pure nitrogen, unconsciousness is almost immediate.

2. Reactivity of the particular cryogenic fluid.- An atmosphere containing more than the normal 21 percent oxygen by volume increases the hazard of fire. Combustion is the process of a fuel reacting with an oxidizer; any increase in the percentage of oxidizer increases the chance of a fire. It also increases the intensity of a fire once it has started and can even involve materials normally regarded as being relatively nonflammable. The rapid expansion of cryogenic methane, ethylene, ethane, or hydrogen when released in the ambient atmosphere can quickly create an explosive situation.

3. Low temperature environment effects on mechanisms and structural materials.- Water or moisture around cryogenic systems create special hazards. The moisture condensed from the atmosphere may freeze mechanisms and render them inoperable. Uninsulated vent lines can cause the formation of liquid air during fill operations with liquid hydrogen, neon, or helium. This formation could prevent normal operation of the vent system by clogging lines with frozen air. Also of special concern are the effects of cryogenic temperatures on the physical properties of the materials of the cryogenic subsystem and other system elements that are in close proximity. Line and pressure vessel ruptures may result from embrittlement of materials at cryogenic temperatures. Leakage may result from dimensional contraction at flange and fitting seals.

4. High pressure potential arising from confinement of liquids and gases.- Because of the great increase in volume of a cryogen as it vaporizes, it is necessary to provide pressure relief valves at strategic points within the cryogenic system. Each pressure vessel or section of line, hose, or pipe that may become isolated and entrap cryogen gas/liquids should be protected by a pressure relief device.

The safety guidelines contained in this section deal specifically with the elimination or control of cryogenic hazards. For broader guideline coverage, reference should be made to section 3.11, PRESSURE SYSTEMS, which covers the generic type safety guidelines relative to pressurized gases and liquids.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.3 SUBSYSTEM CRYOGENICS

ASSOCIATED HAZARD	GUIDELINES
	3.3.1 Design
	3.3.1.1 <u>General</u>
Explosion, Fire, Contamination	a. Cryogenic pressure systems should be marked for easy and immediate identification. Procedures for safe access, monitoring, servicing, and maintenance differ significantly, depending on the chemical and physical characteristics of the fluid.
Temperature Extremes	b. Tank outlet and inlet markings should designate whether the working fluid is vapor or liquid. The hazard potential of opening the system will differ significantly for pressurized vapors and liquids.
Explosion, Temperature Extremes	c. Payload cryogen tank thermal protection systems and tank overpressure vent capacities should be designed for maximum heat rates during ground tanked, in-flight operational, or STS orbit modes including the post abort landing heat soak mode.
Explosion	d. Systems for cryogenics should be free from dirt, lubes, metallic debris, and impurities. System cleanliness is particularly important in cryogenic systems since impurities can become solidified, can cause clogging, or can react chemically with the cryogen.
Fire, Contamination	e. Cryogenic system designs should provide for contraction and expansion resulting from the large temperature differentials experienced during system servicing and operations.
Explosion	f. Cryogenic storage vessels should be provided with sufficient redundancy to prevent hazardous overpressurization. Failure of a single device could allow pressure to increase to a level that would fail the system structurally.
Contamination, Explosion	g. Low points (traps) on cryogenic lines should be avoided to prevent accumulation of contaminants. If traps are unavoidable, drains should be provided.
Corrosion, Illness, Contamination	h. Cryogenic fluorine is extremely hazardous. Particular care in its use should be exercised. Primary safety considerations of any equipment used with fluorine are materials compatibility and cleanliness because of the high reactivity of fluorine with most substances. (See paragraph 3.3.1.4.f for safety considerations).
	3.3.1.2 <u>Storage Vessels</u>
Explosion	a. The space between the inner and outer shells of cryogenic containers should be evacuated to maintain thermal isolation to prevent buildup of pressure between shells. Excessive annular pressure could collapse the inner shell or cause a rupture of the outer shell. Any pressure may degrade the insulating qualities of the two-shell design, resulting in excessive heat transfer and pressure buildup.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.3 SUBSYSTEM CRYOGENICS

ASSOCIATED HAZARD	GUIDELINES
	3.3.1.2 Storage Vessels (continued)
Explosion	b. The annular space should be designed with consideration to the hazardous effects of potential leakage into the annulus.
	3.3.1.3 Venting and Relief
Explosion	a. A normal boiloff vent should be provided where practical on cryogenic equipment and should be maintained at a positive (reference to ambient) pressure to prevent moisture laden air from backfilling and freezing in the vent path.
Explosion	b. Cryogenic pressure vessels or tanks should be equipped with fail-safe pressure relief capability to prevent tank failure. Typical devices providing this capability are pressure relief valves and rupture discs.
Explosion	c. Pressure relief devices should be located so that no section of the system can be isolated from a relief capability.
Explosion, Fire	d. Pressure relief disks should be located so that debris fragments from the disks, if used, will not impinge on or obstruct adjacent plumbing, lines, tanks, cables, or primary structure.
Explosion	e. Rupture disks should be selected with burst pressures, at specified temperatures, within ± 5 percent of the desired relief pressure.
Explosion, Contamination	f. Relief valve outlets should be provided with protective devices to prevent the entrance of contaminants.
Explosion	g. Pressure relief discharge lines should be of sufficient size so that they do not restrict the relieving capacity of the safety device.
Fire, Contamination, Explosion, Corrosion	h. Venting incompatible fluids through a common line could create explosive, combustive, toxic, or corrosive conditions. An analysis should be conducted of the potential effluents within a payload to establish safe vent and relief passages and procedures for nominal and contingency situations.
Explosion, Fire, Loss of Entry Capability	i. Relief devices should be far enough from the tank so that they do not ice up, freeze over, and become ineffective.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.3 SUBSYSTEM CRYOGENICS

ASSOCIATED HAZARD	GUIDELINES
	3.3.1.4 Materials Compatibility
Temperature Extremes	a. Materials that encounter cryogenic fluids should be selected to ensure against structural failure through extreme temperature changes and operating temperatures.
Explosion, Fire, Temperature Extremes	b. Materials for cryogenic service should be selected for compatibility with the specific cryogen and its particular physical and chemical properties.
Explosion	c. All materials used in liquid oxygen systems should be evaluated for impact sensitivity. MSFC-SPEC-106, "Testing Compatibility of Materials for Liquid Oxygen Systems," establishes acceptance criteria of materials for use in liquid oxygen and provides a method to be used in determining the impact sensitivity of such materials. Use of organic materials should be eliminated or reduced to a minimum.
Temperature Extremes, Explosion	d. Transducers in contact with any cryogen should have damping oils omitted and should be calibrated as "dry" units.
Explosion	e. Filter elements for use in liquid oxygen systems should be made of non-oil bearing bronze, Monel or other nonferrous materials to avoid fire or explosion from hydrocarbon contaminants.
Explosion, Fire, Corrosion, Contamination, Illness/Injury	f. If fluorine must be used because of some special property, the following safety considerations should be observed: (1) The requirements of NASA C2-72064, "Fluorine System Handbook," should be followed. (2) Surfaces in contact with fluorine should be free from foreign materials. (3) Welding processes should use inert gas shielding or electron beam techniques to minimize contaminants. (4) Silicone or hydrocarbon base oil filled differential pressure transducers should not be used because of the violent reaction with fluorine if a seal failure occurs. (5) Reaction with frost at service points can be prevented by using an external shroud with a continuous inert gas purge. (6) Controls for pressurized fluorine systems should be by remote means to protect the operator. (7) Special care should be taken to avoid contamination of the atmosphere with the salts of fluorine since these fine powders can be extremely dangerous if ingested.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.3 SUBSYSTEM CRYOGENICS

ASSOCIATED HAZARD	GUIDELINES
	3.3.1.4 Materials Compatibility (continued)
	(8) Fluorine should not be vented through the common STS vent system.
	3.3.1.5 Controls
Temperature Extremes, Injury	a. Manual control handles of cryogenic valves should be insulated so as not to be hazardous (e.g., frostburn or frostbite) to an operator.
Explosion	b. Shutoff valves should not be installed in series with safety relief valves. An erroneously closed shutoff valve could prevent relief of hazardous pressures.
Explosion	c. Valve housing design should prevent vapor pressure buildup to dangerous levels as a result of cryogen leakage into the housing.
Explosion, Fire	d. When payload vent or dump is required, the valves should be remotely controlled from the orbiter or from the ground to provide means of exhausting residual cryogens to vacuum prior to retrieval by the orbiter.
	3.3.2 Flight Operations
Explosion	a. Components in liquid oxygen systems should be maintained at a cleanliness level acceptable for safety system operation. MSFC-SPEC-164, "Cleanliness of Components for use in Oxygen, Fuel, and Pneumatic Systems," is an example of minimum cleanliness levels acceptable for LO_2 system operation.
Contamination, Fire, Explosion, Illness/Injury	b. Toxic, flammable, or corrosive fluids should only be relieved to locations safe for disposal. This could include overboard dump locations or special holding tanks for later disposal.
Explosion, Fire	c. Special hazardous gas detection equipment may be necessary in habitable areas where there is a possibility of the accumulation of toxic, flammable, or corrosive cryogens. This equipment may be provided by the STS or in specific cases may be a payload developer responsibility.
	3.3.3 Ground Operations
	3.3.3.1 General
Contamination, Explosion	a. Liquid hydrogen should be stored in closed containers under 3 to 10 psig pressure to prevent backflow of air into the system.
Illness/Injury, Corrosion	b. Equipment that has contained liquid fluorine or any toxic or corrosive liquid should be purged with dry inert gas (helium preferred) and evacuated to assure removal of the residual fluids.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.3 SUBSYSTEM CRYOGENICS

ASSOCIATED HAZARD	GUIDELINES
	3.3.3.1 General (continued)
Explosion	c. Dye penetrants should not be used for liquid fluorine tank inspection.
Explosion	d. Welding or any hot work should not be done on or near a system containing any of the reactive cryogenics.
Explosion	e. Electrical equipment within 50 feet of a reactive cryogenic facility should be explosion proof.
Explosion, Fire	f. Hazardous gas detection equipment should be used in areas where there is a possibility of free fuel or oxidizer accumulation.
Explosion, Fire	g. The discharge from vacuum pumps handling hydrogen should be ducted to suitable vents to preclude accumulation of combustible vapors.
	3.3.3.2 Test and Checkout
Explosion, Temperature Extremes	a. The design and structural integrity of cryogenic pressure vessels and components should be demonstrated safe by pressure tests.
Temperature Extremes	b. Cryogenic systems should be tested under operating environmental conditions for structural integrity and freedom from leakage.
Temperature Extremes	c. Testing systems with cryogenic fluids is extremely hazardous and should only be controlled and monitored remotely using precautions similar to those for gas leak and pressure testing.
Contamination	d. A post-test vacuum purge should be conducted to eliminate cryogenic fluid entrapment in valves and other system components, and the system should be filled with an inert gas at 5 to 10 psig to preclude system contamination.
Explosion	e. Hydrostatic test fluids for use in cryogenic oxidizer or other systems with LOX (liquid oxygen) clean requirements should pass the LOX impact sensitivity test.

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ELECTRICAL GUIDELINES

3.4 ELECTRICAL

System Description.- The payload electrical subsystem starts at the interface connector between the experiment or payload and the orbiter and includes all electrical/electronic components within that package. Unique portions of the electrical system such as pyrotechnic circuits are covered in the pyrotechnics section, caution and warning has its own section, and controls and displays are found in the human factors section. These electrical subsystem components include connectors, batteries, circuit breakers, cables and wiring, control circuits parts/components/elements, and power systems (including grounding and power distribution system).

Components like cables and wiring, batteries, control circuits, etc., are of concern to the developer only up to the interface furnished by the integrator. Interconnecting cables between payloads, between orbiter and the payload, between IUS (interim upper stage) and payload, and between pallet and payload are furnished by the integrator and are controlled by the ICD (interface controlling document). In the earliest stages of conceptual design, the integrator will obtain information for payload electrical interface definition to determine the payload interface connector requirements, pin assignment, etc. This information will be published in the electrical ICD. Given this interface, the developer also must design and manufacture his instrument to be safe in all environments to which it will be subjected. The electrical relationship of one subsystem to another within a payload involves all circuits (power, signal, command, etc.). Undesirable effects on the circuits include EMI (electromagnetic interference), magnetic, and radiation. Diode isolation, line filters, wire shielding, twisted wiring pairs, and separation of signal wiring from command or power wiring are typical good design practices used to minimize these effects.

Interfaces external to a payload are also quite varied. All the above mentioned factors exist at each interface (i.e., payload-to-payload, payload-to-pallet, payload-to-orbiter, etc.). Each payload, therefore, should be in compliance with the interface requirements of the next higher assembly. Likewise, GSE should be in compliance with applicable interface requirements.

Associated Hazards.- The electrical system can affect a crewman directly by electrical shock or by burns in the event of touching overheated wiring or components. Indirectly, however, the electrical system can cause all types of hazards. For example, a battery explosion could be caused by an internal short or excessive heating caused by failure of a charger to regulate properly. Batteries contain explosive gases which are caustic as well as toxic. Fire could readily result from a failed or improperly selected circuit breaker. High temperature, either by equipment failure or inadequate design, could result in toxic outgassing of materials. High temperature in wiring could melt insulation causing fire and/or circuit crossover to pyrotechnic circuits or actuators resulting in untimely deployment or actuation. Such events could damage the orbiter, other payloads or could injure personnel if they were standing adjacent to such a mechanism. Radiation could become a hazard to a crewman if a laser were turned on because of failure of interlock circuitry or a circuit crossover.

EMI can penetrate cables leading to circuitry and can cause resets, inadvertent start of timing sequences, squib ignition, etc. The man-machine interface requires certain interlocks and safing devices specifically to prevent flight and ground crews from accidently or unknowingly initiating an unwanted event. EMI, which a payload may generate but be insensitive to, may be a significant hazard to other payloads, the pallet or module, and even the orbiter itself.

The following electrical guidelines are provided to assist the payload developer in creating an instrument as free from crew and ground handling hazards as possible.

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SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1 Design
	3.4.1.1 Connectors
All	a. Connectors which are mismated in the process of installation can cause considerable damage to the connector and to the experiment which it powers. In the act of mismating a connector, there is a possibility of unwanted actuation of automatic events, firing pyrotechnics, etc., which in turn could result in damage to the orbiter, injury to personnel, and other unwanted events. The following considerations are presented to help eliminate the more common causes of mismated connectors:
	(1) Plugs and receptacles should be marked or coded to prevent mating in the wrong orientation.
	(2) Plugs and receptacles should be shaped, keyed, or restrained so that it is physically impossible to mismate with adjacent connectors.
	(3) Connector shells should have guides so that alignment occurs without trial-and-error scraping of pins across the female contact to find the alignment position.
Electrical Shock	b. Access to power should be only through female contacts or sockets; the male contact or pin should be without power when unmated.
Electrical Shock	c. Connectors which are scheduled to be mated or demated by the crew during normal in-flight operations should be provided with power removal capability when the load is sufficient to result in pin damage from arcing.
Electrical Shock, Contamination	d. Connectors are susceptible to the environment in many ways. Moisture, loose particles and other forms of contamination can bridge the small gap between pins in a connector if these surfaces are left exposed. Corona can occur between connector pins at reduced atmospheric pressure. Wire flexing eventually can cause an unrestrained connection to break at the connector pin. The following will help reduce the occurrence of these hazard-producing failures:
	(1) Connector back shells should be environmentally sealed or potted with an approved material to avoid particle contamination or breakdown of dielectric due to moisture. Wires should be strain-relieved to avoid breakage due to flexing.
	(2) Connectors should have tethered caps, plugs, or covers to protect against contamination or damage when unmated.
Contamination, Illness, Injury	e. Connectors used within the habitable areas of the spacecraft should have self-locking devices. The use of safety wire is undesirable because of loose particles and sharp wire ends.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.1 <u>Connectors</u> (continued)
All	f. Receptacles whose mating plugs have locking features requiring a twisting motion (bayonet or threaded types) should be positively keyed or pinned to their mounting surfaces so that it is physically impossible for the receptacles to turn during plug attachment.
Explosion, Fire	g. Power circuits should be designed so that power receptacles and connectors located in or used with equipment containing flammable vapor or liquids should be incapable of initiating an explosion by sparking or arcing.
All	h. Payload connectors, internal or external to the orbiter, should be designed to eliminate the possibility of potential damage to crewman life support equipment because of stray electrical voltage or current.
	3.4.1.2 <u>Batteries</u>
All	a. The following are typical battery types for payload sources of power: o Carbon-zinc o Gelled electrolyte o Magnesium-air o Mercury-zinc o Nickel-cadmium o Nickel-hydrogen o Nickel-zinc o Silver-cadmium o Silver-zinc The list includes both wet and dry cells, and sealed and vented type batteries. Many off-the-shelf batteries require additional enclosures, vents, connectors, and markings to make them safe. Batteries should be selected, designed, or modified to be fully qualified for the environments to which they will be exposed during their intended missions.
Explosion, Fire, Contamination	b. Regardless of the type battery selected, the primary hazards are the buildup of hydrogen and oxygen and expulsion of electrolyte. These conditions can be overcome by incorporating the necessary design features and close control of charging and discharging. Mixed hydrogen and oxygen to certain confined volumes and mixture ratios in the presence of an ignition source can result in an explosion. Electrolyte is caustic and electrically conductive. Expulsion of electrolyte can result in a short circuit leading to battery discharge and heating which could result in an explosion.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.2 Batteries (continued)

The following safety guidelines should be considered in the design of battery cells and battery cases:

(1) Cells should be designed to minimize the probability of electrolyte escaping.

(2) Wet cell batteries should have positive pressure relief capability for each cell.

(3) Cells should contain the minimum amount of electrolyte leakage in zerogravity.

(4) Cell cases should be designed to avoid access of electrolyte to vent mechanisms to help prevent electrolyte ejection.

(5) Cell design should include analysis/tests to determine structural capabilities. Annealing of molded plastic cases may be required for stress relief.

(6) An installed battery (single or multiple celled) should be enclosed within a case which will prevent electrolyte leakage into the surrounding area in the event of damage to any of the battery cells.

(7) Battery cases for vented cell systems should be designed to contain all electrolyte during overpressure conditions such as those caused by overload or internal shorts.

(8) A battery case constructed of metal should be internally coated to be resistant to electrolyte attack and the coating should be electrically nonconductive. If a vent plug is installed, it should be electrically isolated from the case by use of an insulating insert.

(9) Battery cases with vent plugs should incorporate provisions to help prevent ejection of accumulated electrolyte, i.e., porous plug, standpipes, etc.

(10) Free volume within battery cases should be decreased to a minimum to reduce the accumulation of gas.

(11) When battery case vents are used, they should be located to preclude damage to adjacent equipment or injury to operating personnel.

(12) Battery cases should not be vented into the habitable areas of the spacecraft.

(13) Exposed circuitry such as relay contacts should not be used inside or adjacent to the battery case. Such components often cause sparking and arcing and can ignite the gaseous mixture which a battery emits.

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SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.2 Batteries (continued)
	(14) Batteries should be designed to preclude polarity reversal when installing connecting terminals. Decals or markings should clearly indicate positive and negative terminals where lug and bolted terminal connections are used.
	(15) Battery connections to main busses should not be of dissimilar metals as corrosion between mating surfaces would likely result.
	(16) Battery connections to main busses should be coated or sealed to prevent exposure of terminals to ambient environment to avoid the effects of moisture.
	(17) Batteries should not be connected with a load applied as sparking and arcing could result.
	(18) Battery cases should be marked to indicate the type of electrolyte and should refer to the appropriate activation and safety procedures.
	3.4.1.3 Circuit Breakers/Circuit Protection Devices
Temperature Extremes, Fire, Electrical Shock	a. A circuit breaker or similar protective device should be provided in each payload to prevent an overload in one payload from affecting other payloads, interfacing equipment, or the orbiter.
Temperature Extremes, Fire, Electrical Shock	b. Circuit breakers should be sized (or set) to protect the smallest wire within all branches of a circuit. Adjustable type circuit breaker settings should have tamperproof settings.
Temperature Extremes, Fire, Electrical Shock	c. Circuit breakers should trip and protect the circuit even if the switch lever is physically held in the "ON" position. Circuit breakers should provide a visual indication when tripped.
Explosion	d. Circuit breakers located in or used with equipment containing flammable vapors or liquids should be sealed against these elements to qualify the breakers as explosion proof.
Temperature Extremes, Explosion, Electrical Shock	e. A redundant circuit should not share the same circuit breaker with the primary circuit.
Fire, Temperature Extremes	f. Circuit protection devices should be sized (or set) so that the combination of current and time at which the device operates will not cause the operation of protective devices between the circuit breaker and power source.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.4 Cables and Wiring (continued)
	(1) The use of a single or multipoint shield ground based on the interference signal frequencies, the length of the transmission line, and the relative sensitivity of the circuit to high or low impedance fields.
	(2) The use of single point shielding, which is effective for short shield lengths. Multipoint shielding, in general, solves most shield grounding problems if there are no large ground currents present in the shield.
	(3) The use of twisted wire pairs to reduce magnetic coupline below 5 kHz (kiloHertz). A highly conductive copper braid shield should be added over the twisted pair, and the shielding should be terminated at the potential of the ground plane to reduce electrostatic coupling.
Collision, Loss of Orbiter Entry Capability	i. The communication subsystem components should be electrically shielded from the electrical power components to prevent electrical transients from inserting errors into telemetry data leading to misinterpretation of payload subsystem status, particularly on automated payloads (free flyers).
All	j. Power and signal (including command) wiring should not be routed through the same cable, cable bundle or wiring harness. This practice may result in voltage induction into adjacent circuits. Induced voltage can be strong enough to fire squibs, reset circuit logic, actuate devices, etc.
All	k. Shielding to protect against induced voltage for frequencies below 50 kHz should be continuous through all connectors and should be grounded at only one end. Above 50 kHz, shielding should be continuous through all connectors and should be grounded at both ends.
Electrical Shock, Temperature Extremes, Fire	l. Wiring splices are undesirable. Splicing allows an unknown quantity of additional single point failures. If splices are required, they should be witnessed, inspected, and recorded as specified in JSC Design Standard No. 88 or equivalent.
Electrical Shock, Injury	m. When power or signal grounds are connected to structures, all grounds should be carried back to the orbiter payload power interface point (see section 3.4.1.6.k, Power Systems).
Electrical Shock, Fire, Temperature Extremes	n. Single strand solid wire should not be used in locations where it may be subjected to flexing as it could break.
Electrical Shock, Fire, Temperature Extremes	o. The use of wire smaller than 22 gauge should be avoided because of its susceptibility to breakage during handling and vibration.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.3 Circuit Breakers/Circuit Protection Devices (continued)
Fire, Temperature Extremes, Electrical Shock	g. Circuit protection devices should be used in all GSE current-carrying conductors which connect to flight hardware (power, control, signal, and returns).
	3.4.1.4 Cables and Wiring
All	a. Wiring penetrations should be potted, sealed, or similarly protected against shorting by materials floating in zerogravity environment and against the effects of liquid leakage or condensation.
Contamination, Corrosion	b. Electrical wire or cable insulated or coated with Teflon TFE (polytetrafluoroethylene) or FEP (fluorinated ethylene propylene) should be etched prior to potting to assure mechanical bond strength and environmental seal. Unetched TFE or FEP wire insulation will not bond properly, and moisture can penetrate within the connector causing dielectric breakdown between pins.
Corrosion, Temperature Extremes, Electrical Shock	c. Potting must be accomplished within 3 weeks after etching or the bond strength will deteriorate.
Temperature Extremes, Fire, Electrical Shock	d. When etching of insulation is required, the process specification should specify that the bare conductor portion of the wire must not be exposed to the etchant and that there are no pinholes in the insulation.
Electrical Shock, Temperature Extremes	e. Cabling and/or wiring exposed to the extreme temperature environment of space should be capable of being flexed without damage.
Explosion, Temperature Extremes, Fire	f. Cables and wiring should be configured, located, clamped, and supported to eliminate any possibility of mechanical stress on wires, wire terminations and connectors, or contact with liquid lines and to remain clear of sharp edges and moving parts.
Temperature Extremes, Electrical Shock, Fire	g. Wires and cables should not be identified or marked by hot stamping directly onto the insulation as this may reduce the integrity of the insulation and cause embrittlement.
Collision, Explosion	h. Critical and hazardous systems should be adequately shielded from RF radiation which can cause possible equipment malfunctions, can initiate ordnance devices, and can present vital communication functions. Design safety consideration should be given to:

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SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.4 Cables and Wiring (continued)
Electrical Shock, Temperature Extremes, Fire, Explosion	p. Electrical cable installations should be designed with sufficient flexibility, length, and accessibility to permit disconnection and reconnection of connectors without damage.
All	q. Electrical wiring insulation should meet the applicable environmental, flammability, and chemical compatibility requirements. Teflon TFE (per MIL-W-22759) and Kapton polyimide (per MIL-W-81381) have been tested and found to meet the flammability requirements. Polyvinyl chloride (PVC) should not be used.
All	r. Circuit breaker/wire gauge size compatibility should be established by analysis.
All	s. Precautions should be taken in clamping, bending or otherwise stressing Teflon covered wire as shorting caused by insulation cold flow could result.
	3.4.1.5 Control Circuits
All	a. When redundancy is required, the redundant control circuit components should be independent of those components used in the primary control circuit.
All	b. When redundant control circuits are necessary, primary and redundant control circuit wiring should not be routed through the same cable or connector.
All	c. When redundant control circuits are necessary, primary and redundant circuits should not be supplied from the same branch power bus or circuit breaker.
Electrical Shock	d. Electrical shock protection circuits should be provided where hardware operation requires electrical interface with the crewman.
All	e. Redundancy should be considered where relays are used in critical control systems.
All	f. Self-test circuits should indicate the actual system response rather than indicate only the initiation of a command or test signal.
All	g. System indicators used to monitor system status should indicate the actual system response rather than indicate only the initiation of a command or application of power.
All	h. Control circuits should include an in-flight checkout capability to verify the independent operation of each circuit.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.5 Control Circuits (continued)
All	i. Redundant control circuits which control hazardous functions should include a self-test or checkout capability.
Fire, Temperature Extremes	j. Safety critical circuits, such as a heater circuit which could experience thermal runaway in operation, should be designed fail-safe.
All	k. Equipment should revert to a safe configuration when an input power loss, overvoltage, or undervoltage condition occurs.
Fire, Temperature Extremes	l. When heating elements are incorporated in ovens or similar environmental chambers, consideration should be given to redundant automatic heater shutoff devices (independent of primary temperature controlling devices) that require manual reset.
All	m. Equipment should be provided with an accessible single main power on-off switch which will remove all power (other than input power to the main switch) from the equipment when the switch is placed in the off position.
Electrical Shock, Injury	n. Circuitry having capacitors which could discharge hazardous current levels should be provided with a bleed-down circuit.
Collision, Injury	o. Redundant circuit protection devices should be used where opening of the primary device would result in a hazard.
All	p. Circuits (including latching relay circuits) should be designed to preclude inadvertent operation due to voltage transients.
Fire, Temperature Extremes	q. When heaters are used primarily for temperature control of experiment components, consideration should be given to independent circuits for temperature sensing, control, and overtemperature protection.
Explosion, Fire	r. Electrical and electronic components located within consoles, panels or similar equipment enclosures containing or exposed to flammable gases, vapors, or liquids should be explosion proof.
Collision, Explosion, Injury	s. Circuit breakers or switches used to control equipment or circuitry intended for emergency purposes should have positive protection against inadvertent operation.
All	t. Loss of control circuit power should not result in the loss of capability to determine the status of the payload.
All	u. Operating range and performance limits for experiments should be specified in the design.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.5 Control Circuits (continued)
Collision, Temperature Extremes, Contamination	v. Cleanliness level and contamination control requirements of electrical/electronics should be specified in the design.
All	w. Automatic relays in safety critical circuits for switching to backup power should respond also to the gradual loss of primary power.
	3.4.1.6 Power Systems
All	a. Capability should be provided to remove electrical power from each experiment interface without affecting the operation of other experiments or systems to permit load selection during emergency conditions.
Fire, Electrical Shock, Explosion	b. The power system overload protective devices should also protect the ground support equipment against damage resulting from a spacecraft power system malfunction.
All	c. Redundant power distribution buses should not be routed through the same connector as a single failure may cause a loss of both buses.
Electrical Shock, Injury	d. Barrier isolation and warning markings should be provided for power sources.
Electrical Shock, Injury	e. A power removal interlock should be provided which is activated by removal of access panels or covers during servicing.
Electrical Shock	f. Test points should be provided for safe status monitoring.
Electrical Shock, Illness/Injury, Radiation	g. All external parts of the RF equipment, excluding the driven elements of the antenna and transmission lines, should be at ground potential at all times to prevent undesired radiation and injury to operating personnel from accumulated charges, accidental connections, and stray potentials.
All	h. Direct current returns should not be disconnected or isolated from the single point ground connection to the spacecraft structure during any mode of system, experiment, or other payload operation as voltage transients, EMI, and electrical shock are a few of the hazards which could occur.
All	i. Module, experiment, and other payload cases should be electrically grounded so that a fault current (based on maximum short circuit current that may result from available power within individual equipment) may be safely returned to the spacecraft single point ground.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.5 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.6 Power Systems (continued)
Electrical Shock, Collision	j. Negative control or switching in the power return leads of a component should not be used unless the positive lead is switched simultaneously. An application of this would be reversal of a motor.
All	k. Power and signal returns for flight systems, experiments, or other payloads should be isolated from the chassis and should be routed through connectors or terminals to a single point ground termination for interface with the spacecraft single point grounding system.
All	l. To reduce EMI problems caused by improper or inadequate grounding, the following practices are recommended:
	(1) Bare metal mating surfaces should be cleaned.
	(2) Mating surfaces should be welded when possible; when not, bonding straps should be used to bridge between adjacent pieces of metal.
	(3) Where protective films or coatings are required, it should be ensured that the material is a good conductor.
	(4) The fastening method should be designed to exert sufficient pressure to hold the surfaces in contact in the presence of deforming stresses, shock, and vibrations associated with the equipment and its environment.
	(5) If the surfaces are not inert in their storage and operating environments, surface protection should be provided according to paragraph (3) preceding or other suitable measures should be taken to ensure the maintenance of the bond for the service life of the equipment.
	(6) Paint should not be used to establish an electrical or RF bond.
	(7) Threads of screws or bolts should not be used to establish RF bonds.
	(8) Ohmmeters should not be used to evaluate RF bonds or RF gaskets.
	(9) RF gaskets should be compressed.
	(10) A uniform grounding philosophy should be ensured.
	(11) Ground loops, impedance coupling and floating grounds should be checked.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.6 Power Systems (continued)
	(12) Good electrical bonding practices for ground terminations should be ensured.
All	m. Plug-in tools for use in spaceflight should be compatible with the spacecraft electrical system single point ground (see ICD for details).
	3.4.1.7 Parts/Components/Elements
All	a. Conformal coatings which place stress on glass diodes should not be used. In other applications, the thickness of conformal coating should be closely controlled to prevent stress on components resulting from shrinkage.
Corrosion, Electrical Shock	b. Positive provisions should be specified in the design to preclude seepage of conformal coatings into electrical interfaces in stud-mounted semiconductor installations.
All	c. Circuit boards, terminal boards, switches, relays, and similar components should be potted, sealed, or similarly protected against the effects of liquid leakage or condensation and against shorting by materials floating in zerogravity environment.
All	d. Electrolytic capacitors such as tantalum wet slug or aluminum/paper should not be used in timing circuits or circuits where capacitance must remain stable with changing voltage.
All	e. Electronic parts and leads should be configured to provide for relief of strain due to thermal expansion and contraction.
All	f. Point-contact, grown-junction or alloy-junction semiconductors should not be used. In general, semiconductors made prior to 1962 are of poor reliability because of physical internal construction, low temperature tolerance, high leakage currents, etc. If it is necessary to use any semiconductors of this vintage, it should be demonstrated that crew safety will not be adversely affected by failure of these components.
All	g. Component selection should be such that the setting, position, or adjustment of controls will not be affected by shock, vibration, or acceleration resulting from launch, separation, or on-orbit operations.
All	h. Equipment requiring adjustment during operation should have external adjustment provisions.
All	i. When ultrasonic vibration is used for cleaning sensitive electronic assemblies, consideration should be given to potential adverse effects.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.1.7 Parts/Components/Elements (continued)
All	j. Polyurethane conformal coatings containing solvents which dissolve polystyrene should not be used on circuit boards containing polystyrene components. A solvent compatibility check should also be conducted to determine compatibility with the printed circuit board materials.
Electrical Shock, Fire, Temperature Extremes	k. Positive mechanical means should be specified in the design to ensure adequate contact pressure is maintained at stud-mounted semiconductor connections.
All	l. CMOS (complementary metal oxide semiconductor) and other static sensitive circuit components should be avoided in safety critical circuits where static discharge, including lightning, is unavoidable. Such lightning conditions are common at KSC, and previous programs such as Viking have experienced a high mortality rate of installed and operating CMOS components because of lightning striking in the vicinity of buildings where the components were in operation.
Electrical Shock, Fire, Temperature Extremes	m. Terminal lugs and insulated washers used with stud-mounted semiconductors should have sufficient matching surface area to ensure that the terminal lug will remain insulated from the mounting structure.
All	n. When electronic components which are sensitive to static discharge are prepared for shipment or environmental protection, caution should be used to avoid material which will induce static electricity.
Contamination	o. Previous experience has shown that sheeting and bagging materials used for protecting flight hardware are susceptible to outgassing of plasticisers at near room ambient conditions. A thorough understanding of the materials used will avoid the undesirable effect of outgassing.
Contamination	p. Care should be used in selecting an inert atmosphere for shipping and storing electronic components. Certain items such as video tubes will absorb helium through the vacuum seal and then not operate when they are to be depended upon.
	3.4.1.8 General
Collision, Injury, Temperature Extremes	When payloads require the use of magnets, the magnetic strength should be investigated for compatibility with orbiter/ payload systems.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.4 SUBSYSTEM ELECTRICAL

ASSOCIATED HAZARD	GUIDELINES
	3.4.2 Flight Operations
Electrical Shock, Explosion, Injury	a. Connectors which are scheduled to be mated or demated by the crew during normal in-flight operations should have power removed at the circuit breaker panel or switch, and power removal should be verified by positive means prior to demating or mating.
Electrical Shock, Collision, Explosion	b. Circuit breakers for a particular system should not be engaged until the system is needed or as late as possible. This reduces the possibility of short circuits, crew shock, inadvertent actuation, etc.
Electrical Shock, Injury	c. Connection and disconnection of solar panel connectors should not be done when panels are illuminated. Solar intensities can generate a high current level, and sparking and arcing could occur.
Electrical Shock, Explosion	d. Solar panel connectors should not be mated or demated until it is verified there is no load connected.
	3.4.3 Ground Operations
Electrical Shock, Explosion	a. Connection and disconnection of solar panel connectors should not be done when panels are illuminated. Some levels of artificial illumination can cause arcing at the connector pins.
Electrical Shock, Explosion	b. Solar panel connectors should not be mated or demated unless it is verified there is no load connected.
All	c. Contemporary space age electronic circuitry is very susceptible to burnout or circuit degradation from exposure to small electrostatic charges. These are easily built up on plastics, insulation, clothing, paper, containers, packing material, etc. The effect is further aggrevated by low humidity. Caution is necessary to prevent discharge of any of these sources of static electricity into sensitive circuitry.

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ENVIRONMENTAL CONTROL GUIDELINES

3.5 ENVIRONMENTAL CONTROL

System Description.- The environmental control consists of thermal insulation, heaters, furnaces, coolant loops, automatic and manual temperature controls, and cooling fans as needed for payload thermal control. It does not include the life support and waste management system for the habitable areas on the orbiter.

The environmental control system will interface with pressure systems and electrical subsystems when payloads require coolant loops, heat exchangers, refrigerants and their related controls. The environmental control system also interfaces directly with payload structures as the payload should not transfer heat into the orbiter structure. Payload equipment generating heat should also be insulated to prevent overheating of adjacent components and payload structures. Thermal measurement sensors may be necessary to alert the crew of impending overtemperature conditions and the need for corrective action.

Associated Hazards.- The hazards associated with the environmental control are contamination, corrosion, fire, illness, injury, and temperature extremes. Insulating materials which shed particles can cause contamination problems in equipment in zerogravity and will contaminate the atmosphere in habitable areas. Leaks of toxic refrigerants into habitable areas can contaminate the atmosphere and lead to crew illness. Materials susceptible to moisture and high humidity may corrode, grow fungus, or cause electrical problems progressing to equipment failures and crew hazards. Inadequate or lack of remote control capability of heaters can lead to fires or temperature extremes and failures of essential equipment. Furnaces must be adequately shielded to protect personnel from burns and they should contain adequate controls for venting and emergency shutdown. Thermal insulation should be provided to protect orbiter structure from temperature extremes caused by heat transfer from heat generating sources.

This section includes guidelines for selection and use of materials or components in the use environment where high humidity, moisture, vibration, and shock will be encountered. Other sections which should be reviewed for additional information are sections 3.2, CAUTION AND WARNING, 3.11, PRESSURE SYSTEMS, and 3.15, STRUCTURES.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.5 SUBSYSTEM ENVIRONMENTAL CONTROL

ASSOCIATED HAZARD	GUIDELINES
	3.5.1 Design
	3.5.1.1 <u>General</u>
Illness/Injury	a. Operating equipment such as pumps, fans, motors, gearing, actuators, and electrical components should not produce noise levels in habitable areas causing crew annoyance and discomfort. Excessive noise levels contribute to crew error or can cause permanent hearing loss. The maximum allowable noise levels of experiments should not exceed the noise criteria standards contained in "Man/System Design Criteria for Manned Orbiting Payloads" (MSFC-STD-512).
Contamination, Illness	b. Materials should be selected which are not nutrients for fungus. The Kennedy Space Center has a natural environment with favorable conditions for moisture and fungus growth. Experiments in habitable areas should not provide a source of fungi contamination. Materials which are nutrients to fungus should be hermetically sealed or treated to render the exposed surfaces fungus resistant.
Corrosion	c. Materials sensitive to moisture which can induce corrosion or electrical problems should have adequate protective coatings.
Collision	d. Payload equipment should be designed to withstand the use environment and should be subjected to simulated environmental tests. Shock mounts and vibration isolators should be provided as necessary.
	3.5.1.2 <u>Thermal Insulation</u>
Temperature Extremes	a. Thermal insulation may need to be provided on payload/orbiter physical interfaces to minimize heat transfer to orbiter structure. In areas where thermal insulation is necessary, thermal coating insulation should be used to minimize heat transfer.
Temperature Extremes	b. Insulation should be used on pallets to minimize heat transfer to the structure. This should be designed for ease of installation and removal to provide thermal control for the attached experiments.
Temperature Extremes	c. Insulation should be used to protect flammable fluids from heat sources. They should also be used in areas where thermal conditions can heat surfaces to which the crew will be exposed or which provide sources of ignition.
Contamination	d. Materials selected for use as thermal insulation should not react chemically with fluids. They should be selected on the basis of their nonabsorbent, nonflammable, and nonshedding characteristics.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.5 SUBSYSTEM ENVIRONMENTAL CONTROL

ASSOCIATED HAZARD	GUIDELINES
	3.5.1.3 Heaters
Temperature Extremes, Injury	a. In equipment requiring heaters, consideration should be given to use of redundant control circuitry to prevent overtemperature.
Temperature Extremes	b. The design of equipment requiring automatic heater control should contain provisions for automatic shutoff for off-nominal high temperature conditions.
Temperature Extremes, Fire	c. Temperature sensors should be provided as necessary to indicate overtemperature conditions or when safe limits are exceeded. Automatic shutoff devices should be provided to shut off the input energy sources.
Fire, Contamination, Temperature Extremes	d. Equipment such as furnaces which must operate at high temperatures in the presence of flammable materials should be provided with purging and fire suppression devices. Purging provisions should vent combustion products and gases outside the habitable area.
Fire, Temperature Extremes, Illness	e. Incubators used for bacterial studies should be designed with the means to remove the power when temperature limits are exceeded. Mechanical or procedural controls should be available to prevent inadvertent release of bacteria.
Contamination, Illness	f. Materials selected for use in heaters, furnaces, and other thermal equipment should not emit toxic fumes or foul odors into the habitable area.
	3.5.1.4 Thermal Control
Injury, Temperature Extremes	a. In designing experiments to be installed in habitable areas for crew operations, the touch temperature of front panels and controls should not exceed $45^{\circ}C$ ($113^{\circ}F$).
Fire, Contamination	b. In designing thermal controls using coolant loops, refrigerants should be selected which are nontoxic and nonflammable. Coolants should be selected for thermal and physical characteristics over the entire operating range and should be compatible with the metals and materials of heat exchangers, piping and pumps.
Temperature Extremes	c. Heat sensitive components should not be located in high temperature areas or adjacent to equipment radiating heat.
Fire, Injury	d. When fans are used to circulate coolant air, manual controls should be included to deenergize the fan for servicing and also for fire control.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.5 SUBSYSTEM ENVIRONMENTAL CONTROL

ASSOCIATED HAZARD	GUIDELINES
	3.5.1.4 <u>Thermal Control</u> (continued)
Injury	e. Equipment exposed to space environments in sealed canisters which will be retrieved should labeled with appropriate caution and warning.
Injury, Fire	f. Cooling ducts, fans, cold plates or coolant loops should be located to provide uniform and adequate cooling without creating "hot spots" which can lead to fire hazards or potential crew injuries from burns.
Injury, Temperature Extremes	g. Debris guards, screens, filters, and similar protective devices should be located at inlets to ducts, mounted fans, coolant pumps, and other similar components to prevent clogging of these devices.
Contamination	h. Heat exchangers should be located outside habitable areas to minimize heat loads and to eliminate one source of potentially hazardous leakage of fluids.
Temperature Extremes, Contamination	i. To minimize leakage, the use of B-nuts in fluid lines of thermal control equipment should be avoided. Maximum use of brazed or welded joints is preferred.
Temperature Extremes, Contamination	j. Coolant loop connect and disconnect fittings should be keyed and marked to remove the possibility of incorrect line connections.
	3.5.2 Flight Operations
	None
	3.5.3 Ground Operations
Contamination	Coolant loops should contain provisions for accessible fluid loading and contamination control during ground operations.

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HUMAN FACTORS GUIDELINES

3.6 HUMAN FACTORS

System Description.- Human factors include those potentially hazardous interfaces between man and machine. Human capabilities and limitations are prime safety considerations when evaluating the design safety of hardware which requires human operation or handling. Elements of payload equipment which require direct human interfaces are represented by controls (switches, breakers, levers, knobs, etc.), displays (gages, meters, cathode ray tubes, etc.), and equipment requiring ground and flight crew operations for maintenance, servicing, repair or replacement, and normal operations.

The human capabilities and limitations which are important factors to be considered in the design of safe equipment involve the senses of sight, hearing, and touch. Others deal with human characteristics such as physical strength, reach limits, manual dexterity, and reaction time.

The environments in which human beings are expected to operate must be considered for factors which affect human safety. For example, adequate lighting must be provided for efficient visual perception. Noise levels must be minimized since high noise levels can reduce crew efficiency, can contribute to performance errors, and can even cause permanent loss of hearing. High frequency low amplitude vibration is often detrimental to the performance of mental and physical tasks. The unique effects of weightlessness must always be considered during on-orbit operations. Various types of harmful radiation sources also affect human safety. Radiation safety guidelines are covered in detail in section 3.14 of this document.

Associated Hazards.- The basic hazards associated with the human interfaces with hardware involve crew injury or illness from electrical shock, burns from contact with exposed high temperature components, cuts and bruises from contact with sharp edges or moving parts, and ingestion of small loose objects or space debris. Other basic hazards such as fire, explosion, or contamination can be caused by human error or by inadequate hardware design or operations which contribute to human error.

To minimize the effects of these human interface hazards, the following contributors to human error must be considered in the design and operation of payload elements:

a. Excessive physical demands.

b. Unnecessary distractions.

c. Inadequate or unnecessary display of information.

d. Difficult, complicated, and dangerous tasks.

e. Harsh or unpleasant working environment.

The guidelines contained in this section outline various methods to avoid these human interface type hazards. They are organized by payload hardware elements which are directly operated, handled, or interfaced by the crewmen. For further information regarding human capabilities and their influence on design safety, reference should be made to "Man/System Design Criteria for Manned Operating Payloads" (MSFC-STD-512) and "Human Engineering Guide for Equipment Designers," Library of Congress Catalog Card No. 54-8698.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.6 SUBSYSTEM HUMAN FACTORS

ASSOCIATED HAZARD	GUIDELINES
	3.6.1 Design
	3.6.1.1 <u>Controls and Displays</u>
Injury/Illness	a. It is preferable not to use glass or other shatterable materials on manned spacecraft. If these materials must be used in applications such as gages, indicator faces, cathode ray tubes, etc., they should be covered with solid materials such as Lexan polycarbonate to protect the crew from broken particles.
Temperature Extremes	b. Equipment which could cause burns by inadvertent personnel contact should be shielded, isolated, oriented away from personnel, or labeled to warn them of the danger. The continuous touch temperature of front panels and controls requiring manual operation should not exceed 45°C (113°F). Equipment which may retain heat in excess of this limit should not be located where personnel contact is possible or should be labeled to warn the crew of this hazard.
Explosion	c. Electrical and electronic components located within consoles, panels, or similar enclosures containing or exposed to flammable vapors or liquids should be explosion proof. If any such flammable material is allowed onboard the manned spacecraft, it should be contained in nonflammable equipment enclosures.
Electrical Shock	d. Conductive surfaces of equipment touched by the crew (knobs, handles, levers, switches, panels, etc.) should be grounded and insulated to preclude personnel shock or burn. Also, such equipment should not be located close to high voltages.
Injury/Illness	e. Viewfinders and similar crew sighting equipment should incorporate filters or automatic aperture controls to limit the amount and type of light seen by the crewmen to avoid retinal damage.
All	f. Adequate lighting is essential for the efficient visual presentation of information and to ensure safe task performance by crew personnel. MSFC-STD-512 represents the prime source of design and safety criteria for the proper illumination of equipment and areas.
Injury/Illness	g. Noise can cause annoyance and discomfort, can reduce the efficiency of crew performance, can contribute to crew error, and can even cause permanent hearing loss. The maximum allowable noise level of experiments and payload elements should not exceed the noise criteria standards contained in MSFC-STD-512.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.6 SUBSYSTEM HUMAN FACTORS

ASSOCIATED HAZARD	GUIDELINES
	3.6.1.1 Controls and Displays (continued)
Injury/Illness	h. Controls, indicators, and displays (especially emergency or contingency type controls for safing, alarm, or corrective action) should be clearly marked and labeled and should be readily accessible to operating personnel to indicate the system function for each switch position or operation.
Injury/Illness	i. Any control function which could cause personnel injury if operated at the wrong time should be identified in the design, and precautions should be taken to minimize this type hazard.
All	j. Identical controls, such as switches located on the same panel, should be distinctly identified or specifically marked and should not be located near each other when these controls perform different functions and improper switch selection could result in a hazardous situation.
All	k. Control switches requiring coverguards should have the coverguard designed or switch nomenclature located so that the position of the switch can be determined without moving the coverguard.
Injury/Illness	l. The use of switches which do not indicate their on-off positions should be avoided. An example of this type switch includes a self-latching function switch, such as a pushbutton switch, which may be operated without indicating the switch position during the power-off phase. Another type to be avoided is a spring-loaded-to-center switch which controls latching relays.
All	m. Payload controls which are critical to crew or shuttle safety should be shielded, guarded, or located so they cannot be accidentally struck or moved.
All	n. The size, shape, spacing, and location of control switches, handles, levers, etc., should allow for human capabilities and limitations when operating these devices. For example, if a crewman is wearing a spacesuit and gloves at the time, allowances should be made for his restricted movements and limited dexterity in manipulating control devices.
Injury/Illness	o. The setting, position or adjustment of controls should not be affected by shock, vibration, or acceleration resulting from space vehicle launch, docking operations, deployment handling or deorbiting and landing. Methods to accomplish this could include the use of detents, keyed shafts, locking devices, tension springs and switch guards.
All	p. Handles, knobs, and levers on rotary controls should be keyed or shaped to prevent turning on their shafts. Also each rotary control assembly should be keyed or pinned to its mounting surface to prevent simultaneous rotation of the handle, shaft, and control assembly.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.6 SUBSYSTEM HUMAN FACTORS

ASSOCIATED HAZARD	GUIDELINES
	3.6.1.1 Controls and Displays (continued)
Injury/Illness	q. Handles, knobs, latches, levers, etc., requiring alignment or adjustment should have alignment indices or visible markings to ensure proper alignment and adjustment including realignment in flight. The alignment markings should be visible without removal of any component.
Injury/Illness	r. Washers or spacers used in conjunction with knobs, handles, locking pins, and similar devices should be designed to prevent unintentional removal. The presence of debris in zerogravity can create a hazard ranging from minor irritation to a crewman to failure of an orbiter system function due to jamming or interference with its component parts (ingestion into rotating machinery).
Injury/Illness	s. Redundant automatic shutoff devices should be provided for equipment where the buildup of energy could result in a catastrophic situation. Examples of such equipment are turbines which could run away, ovens, or similar environmental chambers incorporating heating elements and pressurization systems.
All	t. As a design goal, direct pressure readout gages should not be used. A rupture or failure of the gage or feedlines would release the measured fluid or gas into the area under full-line pressure, and the operating personnel could sustain injury from flying objects released from the failed gage. Pressure transducers are an excellent replacement for direct readout gages.
Injury/Illness	u. If the use of direct pressure readout gages is unavoidable, these gages should incorporate proper sized blowout plugs. The blowout plug should be positioned so that the direction of discharge will not injure personnel or damage adjacent equipment. To prevent contamination of the area, a pressure relief valve, instead of the blowout plug, could be installed at the gage and an overboard drain line connected to the relief valve. Also, the panel plate or bracket used to mount direct pressure readout gages should not interfere with the operation of the blowout plug.
All	v. Instrument displays should provide accurate, legible, and clear information for use by crewmen to interpret correctly equipment performance and status and to react as necessary to continue operation of this equipment.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.6 SUBSYSTEM HUMAN FACTORS

ASSOCIATED HAZARD	GUIDELINES
	3.6.1.1 Controls and Displays (continued)
All	w. Pressure gages, temperature gages, and similar readout devices should indicate normal system operating conditions in the center 50 percent of the total range of the gage or device.
Injury/Illness	x. System indicators used to monitor status should indicate the actual system response rather than the initiation of the command or the application of power. An example of this could be the indication of actual extension of an antenna rather than just the command to extend.
All	y. The identification and marking of payload components should include color coding to indicate marginal or hazardous range limits. Accepted orbiter standards for color coding are MIL-STD-1247B for flight equipment, MIL-STD-101B for ground equipment, and MIL-STD-1472 for orbiter cabin equipment.
All	z. To assist the operating personnel in correct interpretation of information, all control and display nomenclature should use standardized words, abbreviations, symbols, and acronyms which are commonly understood throughout the Space Shuttle Program.
Injury/Illness	aa. Containers such as film containers which may be pressurized (usually with inert gas) should have a positive pressure indicating device. Opening containers which are under positive pressure could result in injury from flying covers or doors. Also, a device should be provided to sense leakage of an appreciable amount of inert gas into an inhabited area to avert possible hypoxia problems.
All	bb. Caution and warning placards, labels, decals, and tape should be properly positioned, plainly visible, and should display the necessary information to protect the crew from impending hazardous situations. The following caution and warning aids should be considered: (1) Labels and placards should be plainly visible under both light and dark conditions. (2) Caution and warning indicator lights should be located to be readily visible to crew members at their stations. (3) Alarms should be located so they can be heard directly by the crewmen.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.6 SUBSYSTEM HUMAN FACTORS

ASSOCIATED HAZARD	GUIDELINES
	3.6.1.1 Controls and Displays (continued)
	(4) Examples of parameters and elements on which placards or labels are necessary include high voltage sources, rotating machinery, pressurized containers, explosives, flammable materials, critical operations which should or should not be performed, load limits, etc.
	3.6.1.2 Other Equipment Interfaces
Injury/Illness	a. The use of ductile materials, energy absorbing devices, shields, rounded corners, and flush mounted features is recommended to eliminate or prevent accidental contact with sharp surfaces or protrusions. Sharp surfaces or protrusions include edges, crevices, points, burrs, wire ends, screw heads, corners, brackets, rivets, braided cable, cable swages, cable strands, clamps, pins, latches, lap joints, bolt ends, lock nuts, etc., which if contacted, could injure the crew. Areas where exposed surfaces or protrusions can be especially hazardous are the inhabited areas of the space vehicle, transfer tunnels, hatchways, and the areas of the payload bay when extravehicular activities will be performed.
Injury/Illness	b. If protruding equipment such as hoses, wave guides, cables, brackets, etc., cannot be eliminated, it should be made to be removable during service or maintenance functions.
Contamination	c. When not in use or during temporary removal, loose objects such as caps, screws, access doors, tools, locking pins, knobs, handles, lens covers, and similar devices should be contained or restrained. It is also recommended that these items be tethered or held captive to the equipment with which they are used.
Contamination	d. Chains, beaded links or similarly segmented devices are not recommended for use as tethers or restraints since they add to the potential for debris and loose objects.
Injury/Illness	e. Drawers should be equipped with restraining devices and stops to prevent accidental opening or removal of the drawer.
Fire	f. As a fire suppression measure, payload equipment which is to be installed in manned compartments should be accessible to manual fire extinguishers.
Injury/Illness	g. Openings (slotted or otherwise) in cabinets, covers, and similar enclosures through which fire extinguisher nozzles, levers, shafts, and other controls operate should be provided with nonflammable protective covers, boots, or sliding plates to prevent injury or equipment damage resulting from inadvertent insertion or entry of foreign objects. If ventilation holes are used in equipment housing covers, they should be screened or caged to preclude inadvertent insertion of any object which might touch high voltage sources or moving parts.

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SECTION NO. 3.6 SUBSYSTEM HUMAN FACTORS

ASSOCIATED HAZARD	GUIDELINES
	3.6.1.2 Other Equipment Interfaces (continued)
Injury/Illness	h. Handles, controls, and fasteners for mechanisms such as hatches, access doors, folding platforms, or legs should be designed with sufficient clearances to prevent injury to fingers and hands. Allowances should be made for a crewman wearing gloves or a spacesuit (see MSFC-STD-512).
Injury/Illness	i. Wherever possible, equipment requiring adjustment during its operation should have external adjustment provisions.
Electrical Shock	j. The sizes and shapes of equipment enclosing covers or cases should be carefully considered to preclude damage to wiring and other components when the cases are removed or replaced. Wire damage could result in short circuits and possible shock hazards to the crew.
Electrical Shock	k. Racks, chassis, and compartments which contain exposed terminals and similar components should be clearly marked or placarded to indicate the highest operating voltage potential present.
Contamination	l. Any equipment which supplies or releases a gas which can be inhaled should include a filter as the last component in the line. The breathable atmosphere should be free from particulate matter to preclude possible ingestion of such matter.
Injury/Illness	m. Alignment guide pins or slides should be located on panel, drawer, and chassis subassemblies to prevent their contact with exposed terminals during installation and removal operations.
Injury/Illness	n. The use of friction-type locking pins should be avoided in applications where repeated cycling could degrade their locking capabilities.
Injury/Illness	o. Moving parts such as fans, belt drives, turbine wheels and similar components that could cause personnel injury or equipment damage due to inadvertent contact or entrapment of floating objects should be provided with guards or other protective devices.
Injury/Illness	p. Pressure vessels, pressure lines and other hazardous equipment or components should be protected from damage by dropped tools, slipping wrenches, drills, or overlength bolts and screws.
Injury/Illness	q. Installed assemblies (black boxes, etc.) should be provided with debris shields to prevent entrapment of small pieces of equipment or debris behind the assemblies.
Injury/Illness	r. Guards or covers should be provided over all termination points where voltage potentials exist in excess of 35 volts rms or dc with respect to ground if access is possible with voltage applied.

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SECTION NO. 3.6 SUBSYSTEM HUMAN FACTORS

ASSOCIATED HAZARD	GUIDELINES
	3.6.1.3 Tools
Injury/Illness	a. Payload servicing, maintenance, or repair tools should meet the following criteria to minimize the possibility of crew injury or adjacent equipment damage.
	(1) Common commercial tools should be used whenever possible. Complex tools should be avoided. It is an STS design goal to provide commonality of tools for all elements.
	(2) Temporary restraints should be used for individual tools to prevent misplacement or loss in a weightless environment. Only essential tool accessories should be specified since items such as ratchets, extensions, pins, etc., are easily lost.
	(3) The torque values for all threaded fasteners and fittings should be specified in the design, and assembly, installation, and test personnel should be well trained to follow these requirements.
	(4) For spares replacement and contingency maintenance, storage bags, restraining straps, instructional decals, tape, spare nuts and bolts, fasteners, sealants, etc., should be provided.
	3.6.2 Flight Operations
	None
	3.6.3 Ground Operations
	None

INDEX
HYDRAULICS GUIDELINES

3.7 HYDRAULICS

System Description.- Hydraulic systems consist primarily of pumps, actuators, reservoirs, control valves, filters, lines, connectors, and hydraulic fluid. The safety guidelines in this section cover generally only these component types which are unique to hydraulic systems.

The choice of hydraulic fluid for a particular application should be carefully made since it will influence the design and operational characteristics of the system which in turn will affect system safety. For example, some fluids are fire resistant while others are not. Some fluids work well at low temperatures but not at elevated temperatures. Others may have toxic or corrosive properties. These and other properties of various hydraulic fluids are shown in Table 3.7-I. These characteristics may be useful to the payload designer in selection of hydraulic fluids.

Associated Hazards.- The primary hazards associated with hydraulic systems involve the unplanned release of pressurized fluids by leakage or rupture and by failure or inadvertent response to commands due to system deficiencies or malfunctions. Misoperation during test and checkout or maintenance, due to operator error or inadequate procedures, can also be hazardous and can result in injury to personnel or damage to equipment.

Leakage or rupture of a hydraulic system may initiate a chain of events resulting in loss of a critical control function such as may be required to retract a payload element back into the orbiter payload bay. It could result in a fire if the leaking or lost fluid is flammable and contacts an ignition source in the sensible atmosphere. If a system bursts or an explosion occurs, metal fragments may strike and injure crewmen or may damage a critical STS component which may compound the failure. The release of hydraulic fluid may result in electrical malfunctions due to shorting of contacts or connectors. The fluid may have toxic properties and affect exposed personnel to respiratory, eye, or skin irritation, or burns.

Internal failure of a hydraulic system may be caused by unchecked contamination because of clogged or mislocated filters. Bubbles may form in the fluid lines because of poor sealing, or components may seize. The results of these malfunctions may cause erratic response of servo devices or control valves which could further result in system failure to perform some critical function.

The following guidelines indicate how such hydraulic system hazards may be eliminated or reduced to acceptable levels.

The design, test, and operational requirements of hydraulic systems, and the various properties and qualities of hydraulic fluids are covered in detail by MIL-H-5440F. The orbiter baseline hydraulic fluid specified in MIL-H-83282A is also recommended for use on payload applications. For more complete guideline coverage, reference should be made to section 3.11, PRESSURE SYSTEMS, which covers all generic-type safety guidelines relative to any pressurized system.

TABLE 3.7-I. - HYDRAULIC FLUID CHARACTERISTICS

PROPERTY OR QUALITY	PETROLEUM OIL	PHOSPHATE ESTER	PHOSPHATE ESTER BASE	CHLORINATED HYDROCARBON	SILICONE BASE	WATER GLYCOL	SOLUBLE OIL IN WATER	WATER IN OIL EMULSION
SPECIFIC GRAVITY	0.85 to 0.90	1.15	1.08 to 1.35	1.30 to 1.45	1.25 to 1.30	1.10	1.0	0.90 to 0.95
VISCOSITY RANGE	Low to very high	Low to high	Low to high	Low to high	Low to high	Low to high	Low	Low
VISCOSITY INDEX	High	Low to high	Low to high	Low to high	Very high	Very high	Very high	High
TEMPERATURE LIMITS	0° to 275° F (-18° TO 135°C)	Below 0° to 130°F (-18°TO 54°C)	+15° to 130°F (-10 TO 54°C)	+45° to 130°F (7° TO 54°C)	From -65° to 500°F (-54° TO 260°C)	Below 0° to 120°F (-18° TO 50°C)	50° to 120°F (10° TO 50°C)	50° to 120° F (10° TO 50°C)
FIRE RESISTANCE								
Open Flame	Poor	Good	Good	Good	Fair	Very good	Excellent	Fair
Hot Surface	Poor	Very good	Very good	Very good	Fair to good	Good	Excellent	Fair
Auto-Ignition Temperature	700°F (370°C)	1100°F (590°C)	1100°F (590°C)	1200°F (650°C)	850° to 900°F (450° TO 480°C)	—	—	—
STABILITY (Oxidation resistance)	Very good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Good
LUBRICITY	Excellent	Excellent	Excellent	Excellent	Limited to good	Very good	Limited	Good
CORROSION PROTECTION	Very good	Very good	Very good	Very good	Good	Good	Fair	Good
COMPATIBILITY	Excellent	Very good except coatings and water-absorbing materials	Very good except coatings; need special packings	Very good except coatings; need special packings	Generally very good; special packings for high and low temperature	Very good except coatings and water-absorbing materials	Very good except coatings and water-absorbing materials	Very good except coatings and water-absorbing materials
PUMP WEAR								
Balanced Vane	Excellent	Excellent	Excellent	Excellent	Fair to good	Very good	Very poor	Good
Gear Pump with Bushings	Excellent	Excellent	Excellent	Excellent	Fair to good	Excellent	Very poor	Excellent

(FROM AFSC DH1-6 DESIGN NOTE 4C2)

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SECTION NO. 3.7 SUBSYSTEM HYDRAULICS

ASSOCIATED HAZARD	GUIDELINES
	3.7.1 Design
	3.7.1.1 General
Contamination, Corrosion	a. Hydraulics system components should operate safely when subjected to the simultaneous extremes of temperature, pressure, vibration shock loading, and other environmental conditions which will be experienced during all phases of an operational mission.
Fire, Explosion	b. Hydraulic systems should be integrated with other systems to minimize hazards caused by proximity to combustible gases, heat sources, electrical equipment, etc. A single failure in any such adjacent system should not cause a hydraulic system fire.
Fire, Explosion, Contamination	c. Redundant hydraulic components or subsystems should be physically separated for maximum safety against damage from fire, rupture, shock, or any hazard which could affect both segments.
Fire, Explosion, Contamination	d. Hydraulic lines, drains, and vents should be separated from other high energy sources including heat, gases, electrical current, and chemicals.
Corrosion, Fire, Contamination	e. The choice of which hydraulic fluid to use in a particular hydraulic system will affect all elements of design and can be highly important from a safety standpoint. The orbiter baseline hydraulic fluid is specified by MIL-H-83282A, and the various design and operating requirements for hydraulic fluids are specified in MIL-H-5440F. The following hydraulic fluid characteristics should be considered to assure compatibility with system design and operations: (1) Fire resistance. (2) Compatibility with seals, gaskets, fittings, hoses, etc. (3) Temperature range for effective operation. (4) Lubricating compatibility with moving parts. (5) Corrosive properties. (6) Stability.
Explosion, Fire, Contamination	f. Parts of a hydraulic system or attached subsystems that operate on pressures lower than the full system pressure should withstand full system pressure. If this is not practical, relief valves should be added for protection of such components.
Explosion, Contamination	g. Peak pressures (surges, spikes, ripples) should not be allowed to exceed 135 percent of the main system's operating pressure (unless program requirements specify otherwise).

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.7 SUBSYSTEM HYDRAULICS

ASSOCIATED HAZARD	GUIDELINES
	3.7.1.1 <u>General</u> (continued)
Corrosion, Contamination, Fire	h. The operating temperature range of a hydraulic system should be established early in the system design because of the impact this parameter will have on the selection of critical components such as hydraulic fluid, pressurizing gas if used, oil coolers, gaskets, seals, valves, and servos. Embrittlement of seals, erratic valve and servo operation and deterioration of the hydraulic fluid are examples of hazardous interactions caused by excessive temperatures.
Injury, Contamination, Fire	i. Hydraulic equipment or lines should not be located within inhabited areas of the space vehicle.
Electrical	j. Hydraulic system components and lines should be electrically bonded to metallic structure.
	3.7.1.2 <u>Pumps and Actuators</u>
Explosion, Fire, Contamination	a. Hydraulic pumps should be protected from damage by the use of overload devices, bypass relief devices, vibration sensitive cutoff switches, pump suction pressure interlocks, and overload controls.
Explosion, Contamination, Fire	b. Other safety oriented features which should be considered to prevent damage to hydraulic pumps with consequent danger to the crew or STS elements include:
	(1) Use of adequately sized bearings to withstand axial and side loading.
	(2) Protection of pump from contamination by installation of correctly sized filter elements.
	(3) Protection of the pump from cavitation because of low fluid levels or leakage.
Explosion, Contamination	c. Design of lock valves used on hydraulic actuating cylinders should allow for fluid expansion throughout the anticipated temperature range.
	3.7.1.3 <u>Tubing, Lines, and Hoses</u>
Contamination, Corrosion	a. Aluminum alloy, stainless steel, and titanium are prime materials for use as hydraulic system tubing and piping. Work hardening of aluminum, however, should be guarded against. Copper is not recommended because of possible chemical reactions. Galvanized piping is not recommended because of the flaking properties of galvanized material. Lines exposed to heat or abrasion should be fabricated from stainless steel.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.7 SUBSYSTEM HYDRAULICS

ASSOCIATED HAZARD	GUIDELINES
	3.7.1.3 Tubing, Lines, and Hoses (continued)
Contamination, Fire	b. Straight lines between the two rigid connection points should be avoided. Semiloops or flex hoses should be used to ease alignment stresses.
Contamination, Fire	c. Flex hose should be used between any two connections where relative motion can be expected to fatigue metal tubing.
Contamination	d. Materials used in flex hose construction should be compatible with the particular hydraulic fluid used and with the environment.
Contamination, Fire	e. Flex hose installations should be made to avoid abrasive contact with adjacent structure or moving parts. Rigid supports should not be used on flex hose.
Contamination	f. Teflon is preferred over rubber for construction of hydraulic hose. The advantages of Teflon include:
	(1) Much better compatibility with the hydraulic fluids currently in use.
	(2) Chemically inert and anti-adhesive properties.
	(3) A wider operating temperature range.
	3.7.1.4 Connectors
Contamination, Fire	a. To minimize leakage of potentially hazardous fluids, all tube fittings, except where system entry points are needed, should be permanently joined. Welded or brazed construction is preferred over threaded or flared assembly.
Contamination	b. Friction-type locking devices should be avoided in safety critical applications. Safety wiring and self-locking nuts are examples of safe design; star washers and jam nuts are examples of poor design.
Explosion, Contamination	c. Retainer or snap rings should not be used in hydraulic systems where a "blow apart" failure would result.
	3.7.1.5 Filters
Explosion, Contamination	a. Circulating hydraulic fluid should be filtered on the downstream side of the pressure pump. Filters should not be installed in the suction side of pumps unless test data show that pressure drops will not interfere with system operations.
Contamination, Fire	b. Pump case drain fluid should be filtered before it is allowed to enter the return side of the system.

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SECTION NO. 3.7 SUBSYSTEM HYDRAULICS

ASSOCIATED HAZARD	GUIDELINES
	3.7.1.5 Filters (continued)
Contamination, Fire, Explosion	c. Test points or vents are prime sources for system contamination and should be protected by downstream filters.
Explosion, Fire, Loss of Orbiter Entry Capability	d. Standard safety criteria state that critical hydraulic systems should be essentially free from contaminants of larger particle size than will pass through a 10 micron filter. Critical hydraulic systems would include those used to extend, retract, or deploy payloads beyond the payload bay moldline. Failure of such a system could affect the orbiter's capability to return to Earth.
	3.7.1.6 Seals and Gaskets
Contamination, Fire, Corrosion	The hydraulic system's sealing materials should be selected on the basis of the type of hydraulic fluid used, its temperature and pressure, and the type motions required of the seal.
	3.7.1.7 Reservoirs
Explosion, Fire, Contamination, Injury	a. Hydraulic fluid reservoirs should be operable in a weightless environment and should not rely on gravity feed. The reservoirs should be equipped with shutoff valves which are operable from a safe distance in the event of a hydraulic system emergency. The reservoirs should be designed so that they do not become overpressurized.
Explosion, Fire, Injury	b. Hydraulic fluid reservoirs should be isolated from heat sources and from other potentially high-energy sources such as pressure vessels. The intent is to minimize personnel injury or material damage in the event of a rupture.
Contamination	c. Hydraulic reservoir air pressurization lines should include air filters located to protect the pressure regulating equipment from contamination. Other safety oriented considerations to minimize the possibility of contamination include: (1) Use of a fluid filter at reservoir filler openings. (2) Use of tight-fitting filler caps. (3) Avoidance of dip sticks for measuring remaining fluid.
	3.7.1.8 Identification and Marking
Explosion, Fire	a. Components of safety critical systems such as one-way restrictors, flow regulators, and filters should be permanently placarded to indicate the correct direction of installation. Arrows on connecting lines are not considered sufficient identification for this purpose.

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SECTION NO. 3.7 SUBSYSTEM HYDRAULICS

ASSOCIATED HAZARD	GUIDELINES
	3.7.1.8 Identification and Marking (continued)
Explosion, Fire	b. The direction of restricted and unrestricted flows should be indicated directly on restrictor valves.
Injury, Explosion, Fire, Contamination	c. Warning placards, safety tape, color-coded labels and similar hazard identification material should be located in a clearly visible location as close as possible to the affected equipment.
Injury, Explosion, Fire, Contamination	d. Safety critical test information such as pressure limits, hydraulic fluid specification, flow rates, etc., should be permanently posted near test points.
	3.7.2 Flight Operations
	None
	3.7.3 Ground Operations
	3.7.3.1 Test and Checkout
Explosion, Fire, Injury	a. Hydraulic systems should be proof-pressure tested as part of acceptance for flight use. No part of a hydraulic system should fail, take a permanent set, or be damaged in any manner when subjected to proof testing. Proof-pressure levels are established by design specification and will generally be at least 1.5 times the maximum operating pressure for a particular system.
Explosion, Fire, Injury	b. Hydraulic systems and components should withstand flight loading and should retain their capabilities to perform in the operational environments.
Contamination	c. Test points should be provided so that disassembly for test is not required. The test points should be easily accessible for the attachment of ground test equipment. The test connectors should be configured to prevent cross connection.
Explosion, Fire, Injury	d. Externally installed test circuits used during onboard checkout of hydraulic systems should not bypass system pressure relief devices.
Contamination	e. Where necessary, hydraulic system components should contain isolation provision to facilitate independent functional and leak checks of such components without disturbing the total system.
Explosion, Injury	f. Hydraulic systems should have pressure indicating equipment marked to show safe upper and lower limits of system pressure. The pressure indicators should be easily visible to the operating crew.

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SECTION NO. 3.7 SUBSYSTEM HYDRAULICS

ASSOCIATED HAZARD	GUIDELINES
	3.7.3.2 Servicing
Contamination, Fire	a. Self-sealing couplings should be provided on installations which require frequent disassembly.
Contamination, Fire	b. Ground test and servicing ports not required to function in flight should be designed to eliminate leakage during the flight phase.
Contamination, Fire	c. Safety critical hydraulic systems should not require the use of special tools for removal/replacement of components unless the use of such special tools is unavoidable.

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MATERIALS GUIDELINES

3.8 MATERIALS

System Description.- Although the material section does not constitute a functional subsystem, it is a convenient way to group the guidelines for selections and uses of payload materials. The guidelines discourage the use of certain metals and nonmetals in payload equipment if they are to be stowed in habitable areas or if failure can propagate to shuttle systems. Also contained herein are guidelines developed to control the use of materials possessing hazardous properties or characteristics in manned spaceflight operations.

In the confinement of spaceflight habitable areas, toxic products emitted from offgassing materials can readily contaminate the limited atmospheric system and can pose serious threats to personnel. Gaseous products from fabrics, insulation and adhesives can create nauseating and irritating odors. Unrestricted uses of flammable materials also create potential fire hazards. When payload equipment is to be stowed in the orbiter cabin, it must receive the same type material controls as those imposed on cabin materials as specified in NHB 8060.1A, "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments That Support Combustion." The cabin serves as the living quarters and safe haven for the crew. The spacelab and payload bay are not considered safe havens nor are they of equal importance to the orbiter cabin from a materials flammability and toxicity standpoint. Careful consideration, however, should still be given to the characteristics of materials to be located in these payload areas; i.e., offgassing, odor, and flammability.

Integrated payloads will contain fuels, oxidizers, and ignition sources, the three elements for combustion. Flame retardant materials should be selected, if possible, and the location of flammable materials controlled, to maintain the maximum separation for preventing flame propagation. Flammable materials must be prevented from contacting ignition sources by selecting specific locations in the payload, where possible (i.e., separation of oxidizers from fuels, and oxidizers and fuels from propulsive units or electrical circuitry). Efforts should be expended to select materials which are compatible to prevent chemical reactions which may lead to a chance occurrence of fire.

Associated Hazards.- In manned spacecraft operations, hazards associated with payload materials are contamination of the atmosphere from material offgassing; the use of flammable materials leading to fire or explosion; and in case of metals, corrosive problems. (Metal corrosive problems are discussed in section 3.15, STRUCTURES.) Toxic fumes generated by offgassing payload materials located in habitable areas can present serious hazards to personnel. Material offgassing depositions of contaminants on thermal control surfaces can change the thermal characteristics leading to overheating and subsequent component failures. Offgassed material condensing on cold surfaces form conductive paths to other components which may induce subsequent equipment failures. Offgassed contaminants can fog sensitive optical surfaces and can interfere with the operation of interfacing experiments. Use of materials with low fire resistant properties for gaskets, seals, lubricants, coverings, insulation, hoses, etc. should be avoided as they present fire hazards in manned spaceflight operations, particularly in the crew areas where ignition sources and oxygen augment combustion.

The following guidelines have been developed to identify hazards associated with materials. The guidelines are divided into two groups, metallic and nonmetallic materials. The metallic group includes metals which have been found to be hazardous in manned flight operations. The nonmetallic materials group includes elastomers, adhesives, lubricants, insulating materials, chemicals, cleaning fluids, and solvents. In both groups, the guidelines constrain materials for use in the habitable areas. Data on nonmetallic materials which have been tested on previous programs is documented in JSC 02681, "Nonmetallic Materials Design and Test Data Handbook."

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.8 SUBSYSTEM MATERIALS

ASSOCIATED HAZARD	GUIDELINES
	3.8.1 Design
	3.8.1.1 <u>Metallic Materials</u>
Corrosion	a. Aluminum. When selecting aluminum alloys for use with cryogenic fluids or gases, oxidizers, or fuels, consideration should be given to alloys whose heat treatments and coatings minimize the susceptibility to general corrosion, pitting, and intergranular or stress corrosion. Candidate aluminum alloys should be reviewed for compatibility with fluids and gases in the use condition and operating environment.
Contamination, Fire, Explosion	b. Barium. When barium or its compounds are selected for payloads, procedures should be established for safe handling and mission operations. Barium and its compounds have a significant range environment of which toxicity, explosion and fire are possible. Containers with barium or its compounds must be properly marked and adequate in-flight storage provided.
Contamination	c. Beryllium. (1) Unalloyed beryllium should not be used in equipment carried in habitable areas unless it is suitably coated to prevent erosion or formation of salts or oxides. Mist, dust, or fumes containing beryllium are extremely toxic. Uncoated alloys containing 4 percent or less beryllium can be used. (2) If coated beryllium is used in the habitable areas, outgassing tests under use conditions should be conducted to verify that the coating provides satisfactory protection for the beryllium surface.
Contamination	d. Cadmium. The use of cadmium and cadmium-plated parts in contact with breathing gas or in any low atmospheric pressure environment should be avoided. Cadmium will vaporize rapidly at combinations of temperature and pressures encountered in spaceflight applications. Overheating of cadmium or cadmium-plated parts can severely contaminate the atmosphere with toxic fumes. Organic-based paint should not be used as an overcoating barrier for cadmium surfaces because of the porosity of the coating and the possibility of overcoating damage. Cadmium should not be allowed to contact titanium at any temperature because embrittlement can result.
Corrosion	e. Magnesium. Magnesium alloys should not be used except in areas where no exposure to corrosive environments can be expected, and protection systems can be maintained with ease. Their uses should be avoided in areas subjected to wear, handling abuse, foreign object damage, abrasion, erosion, or in areas where fluid or moisture entrapment is possible.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.8	SUBSYSTEM MATERIALS
ASSOCIATED HAZARD	**GUIDELINES**
	3.8.1.1 Metallic Materials (continued)
Contamination, Corrosion	f. Mercury. Mercury should not be used in equipment instrumentation, testing, or calibration of components in habitable areas since it is extremely toxic. Mercury and its compounds can accelerate stress corrosion of aluminum and titanium alloys. When mercury is required, the following information should be documented: (1) A list of equipment containing mercury to be used with justification for each use. (2) The amount of mercury contained in the equipment. (3) How the equipment is protected to prevent release of the mercury. (4) A defined plan to accomplish decontamination if mercury is released.
Explosion	g. Molybdenum. Molybdenum in alloys in excess of 0.05 percent should be avoided for use with fluid and gas systems. The alloys can react violently in contact with hydrazine and amine-based propellants when the fluid boiling point temperature is exceeded. Without exception, material compatibility investigations of these alloys should be performed prior to use.
Explosion, Corrosion	h. Titanium. Titanium or its alloys should not be used where they can be exposed to liquid or gaseous oxygen exceeding two atmospheres of absolute pressure because a violent reaction is possible. Titanium or its alloys should not be used where they can come in contact with methanol. (Methanol may react with titanium and lead to stress corrosion.) Titanium should not be allowed to come in contact with nitrogen tetroxide with water content in excess of 2.5 percent, or a nitric oxide content less than 0.4 percent as intergranular corrosion can be accelerated and in pressurized systems can undergo catastrophic failures. Titanium should not be used in contact with cadmium since embrittlement may ensue. Each environment contacting titanium should be analyzed to be certain that it and titanium are truly compatible.
Explosion, Contamination	i. Any materials under stress whose failure can be catastrophic should be evaluated for potential failure because of incompatibility of materials. For example, the fabrication of tanks for the storage of fluids should have tests run using fracture mechanics criteria and techniques to assure that it is truly compatible under all anticipated storage or use conditions and environments. High performance materials often may be the poorest choices for pressurized hydrogen tanks. Only in cases where there is documented evidence of fluid-material compatibility should there not be fracture mechanics evaluation of the application intended for newly fabricated materials. Fracture mechanics tests should be performed when documented evidence or data showing fluid-material compatibility does not exist.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.8 SUBSYSTEM MATERIALS

ASSOCIATED HAZARD	GUIDELINES
	3.8.1.2 Nonmetallic Materials
Contamination	a. To prevent material failures, elastomer, rubber, and adhesive materials should be selected for compatibility with the use environments of temperature extremes, resistance to heat aging, polymer reversion, and compatibility with the working fluid.
Contamination	b. Materials requiring age control, such as the natural rubbers and some of the polyester urethanes, should be avoided. Their uses may be considered where their service life is equal to the service life of the equipment, or age control is such that replacement is readily accomplished during routine servicing.
Fire	c. Elastomer materials such as Viton and Fluorel should be selected for use as molding compounds, conformal coatings, sprayable coatings, and sponge materials. These elastomers are flame resistant and maintain their elasticity in the space environment.
Fire, Explosion, Collision	d. In safety critical circuits such as pyrotechnics, the use of polyurethane conformal coatings containing solvents which dissolve polystyrene compounds and other materials used on electrical circuit boards should be avoided. Also, the use of conformal coatings which can mechanically overstress components such as glass diodes on safety critical circuit boards should be avoided. In general, caution should be exercised in the selection of conformal coating materials for safety critical wiring boards. Conventional thickness coatings (10-15 mils) (.25-.375 mm) have resulted in damage to components and solder connections (use thin coatings of 2-4 mils (.05-.1 mm) when considered appropriate).
Corrosion	e. For electronic packages, silicone sealants should be selected which will not react with atmospheric moisture to release acetic acid that can cause corrosion.
Contamination	f. CNR (carboxy nitroso rubber) should not be used as a payload material as it liberates appreciable quantities of toxic products when exposed to temperatures exceeding 500°F (260°C).
Contamination	g. When using RTV (room temperature vulcanizing) silicone sealants, and adhesives in electronic packaging, adequate cure time should be specified to prevent liberation of acids during operation. Nonflammable sealants and adhesives should be selected for use on equipment to be located in habitable areas.
Contamination	h. Extreme care should be used in specifying O-rings and similar seals for dynamic applications in cryogenic environments. The use of silicone rubber materials should be avoided as they generally become brittle at temperatures in the neighborhood of –184°F (–120°C). Many generic classes of rubber materials become brittle at even higher temperatures.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.8 SUBSYSTEM MATERIALS

ASSOCIATED HAZARD	GUIDELINES
	3.8.1.2 Nonmetallic Materials (continued)
Fire	i. Silicone elastomer material should be avoided for use with liquid or gaseous oxygen since the elastomer acts as a fuel in pure oxygen. Materials which contain oil or carbon content should be avoided for use in oxygen systems. Chlorinated polyether resins or polyformaldehyde materials should also be avoided for use in oxygen systems.
Contamination	j. In selecting nonmetallic materials to be used as gaskets, seals, O-rings, and packing for oxidizers, propellants, gases and chemicals, these materials should be investigated thoroughly for compatibility to prevent material degradation, chemical disassociation, or violent reactions with the working fluid.
Contamination	k. Materials for seals, gaskets, and O-rings should not cold-flow in the use environment which may produce leaks of hazardous fluids.
Contamination	l. Lubricants should be selected for use with materials on the basis of valid test results confirming the suitability of the composition and the performance characteristics for each specific application including compatibility with the anticipated environment.
Explosion	m. Petroleum based lubricants should not be used in liquid oxygen systems as they react violently.
Explosion	n. Chlorinated fluorocarbon lubricants should not be used in applications where they may come in contact with aluminum or aluminum powder as violent reactions result.
Contamination	o. Lubricants to be used with O-rings or seals, should be selected on the basis of compatibility with the composition of the elastomer in the O-rings or seals, and with the fluid being sealed.
Contamination	p. Minimal and nonirritating offgassing properties should be considered when selecting materials for sealants, gaskets, O-rings, hoses, lubricants, insulation, and adhesives for use in habitable areas. In the design, materials which have to be subjected to offgassing tests should be specified.
Contamination	q. For equipment to be used in habitable areas, wire insulation, ties, identification markers, and protective coverings should be selected that are nonflammable and will not generate toxic fumes when overheated from electrical malfunctions.
Contamination	r. The use of PVC (polyvinyl chloride) should be avoided. Outgassing products of PVC are hazardous and generate products of hydrochloric acid, phosgene, carbon monoxide, carbon dioxide, chlorine monoxide, and acidic carbonaceous coke. The plastic has a low ignition point; in vacuum, it loses plasticizers and becomes brittle.

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SECTION NO. 3.8 SUBSYSTEM MATERIALS

ASSOCIATED HAZARD	GUIDELINES
	3.8.1.2 Nonmetallic Materials (continued)
Fire	s. When Teflon is used on experiments to be located in the habitable areas, it should be assured that no organic materials such as pigments have been added which can cause Teflon to burn. Flammability tests should be required when an untested pigment is added to Teflon.
Fire	t. Hoses made with dichloroethane should not be used in habitable areas where lithium hydroxide is used for CO_2 control. Dichloroethane mixed with lithium hydroxide generates acetylene which is highly flammable.
Fire	u. Highly reactive chemical fluids which can produce toxic fumes or are flammable should not be used in the habitable areas. If use of these materials is unavoidable, they should be stored in containers capable of withstanding operational conditions without rupture or emitting fumes, smoke, or gas. The containers must be adequately labeled with placards describing the hazardous content. Procedures for safe handling in all operations should also be provided.
Explosion	v. Nonmetallic materials for use with fluorine should be carefully selected as they are generally incompatible with fluorine and react violently.
Contamination, Fire	w. Nontoxic and nonflammable hygroscopic materials should be used for moisture or humidity control in experiment canisters.
Injury/Illness	x. Paints or coatings should not be used which can degrade in the use environment and can chip or flake off producing floating particles in the zerogravity environment.
Contamination	y. Paints or coatings which contain carbon black should not be used on equipment to be located in habitable areas. Carbon black will offgas toxic carbon monoxide.
Fire, Contamination	z. Photographic film and recording tapes should be selected which are nonhazardous in their use environments.
Contamination	aa. Printing inks should be selected which will not release toxic fumes in the habitable areas. Suitable containers should be provided (no glass) for storage of these inks in the operating environment.
Fire	bb. Flight data files, records, procedures, and checklists to be used during flight operations in habitable areas should be printed on fire resistant paper.
Electrical Shock	cc. Particular care should be given to the static electricity generation and discharge properties of nonmetallic materials.

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SECTION NO. 3.8 SUBSYSTEM MATERIALS

ASSOCIATED HAZARD	GUIDELINES
	3.8.1.2 Nonmetallic Materials (continued)
Contamination, Illness	dd. Asbestos should be avoided in spacecraft use since it produces fibers that are hazardous to personnel and hardware. Where practicable, other materials should be used in lieu of asbestos.
	3.8.2 Flight Operations
Contamination, Fire, Corrosion	a. When toxic, corrosive, and/or flammable materials are to be handled during flight in habitable areas, safety procedures and safe handling equipment should be provided. The materials should be stored so that failure of the containers will not release the material into the atmosphere. Provisions should be specified for the safe collection and storage of used or spent materials. Their possible chemical or physical interaction should be considered when collected and stored together.
Fire, Explosion	b. The location of flammable, explosive, or gas generating materials should be carefully selected and adequate separation of these materials maintained to prevent ignition and flame propagation.
Fire, Explosion	c. Flammable, explosive, or gas generating materials should not be located in the vicinity of the entrance to habitable areas.
	3.8.3 Ground Operations
Contamination	a. When specifying materials to be used for packaging components or to be used to maintain cleanliness level requirements in clean room applications, compatible materials should be selected for the use environment.
Fire	b. Polyethylene type material should not be used to package components in gaseous or liquid oxygen systems. Polyethylene sloughs particles which are pure hydrocarbon. It can be used as an outer wrapping as it provides good resistance to external fluid contamination provided antistatic type is used.
Fire	c. Nylon should be used for the inner wrapping of components requiring high cleanliness levels with the exception of those for liquid oxygen or gaseous oxygen systems as nylon tends to slough particles. Migrating particles in liquid oxygen or gaseous systems present fire hazards. FEP (florinated ethylene propylene) Teflon is a material that can be used to wrap liquid oxygen or gaseous oxygen components. Caution should be used in selection of these materials as some may be electrostatic generators depending on the material manufacturing specification.
Explosion	d. When specifying cleaning agents for system fluids, adequate information should be provided on the chemical reaction between the cleaning fluid and the system fluids. Certain cleaning agents and strong oxidizers are known to react explosively. For example, strict control and instructions should be provided for the use of halogenated hydrocarbons and nitrogen tetroxide.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.8 SUBSYSTEM MATERIALS

ASSOCIATED HAZARD	GUIDELINES
	3.8.3 Ground Operations (continued)
Explosion	e. For oxidizer systems which must be serviced, complete removal of cleaning agents by flushing oxidizer systems with nonreacting agents should be specified before the oxidizer is reintroduced.
Explosion	f. Fluorinated hydrocarbon solvents should not be used in high pressure or liquid oxygen systems as they may react violently.
Contamination	g. If spillage of mercury has occurred during handling operations with experiments, the equipment should be tested for mercury contamination. If mercury is detected, the source should be isolated, corrective action taken, and the equipment retested and verified free from mercury contamination before release for flight.

INDEX

MECHANICAL GUIDELINES

3.9 MECHANICAL

System Description.- The mechanical subsystem is composed of rotating machinery such as pumps, compressors, turbines, centrifuges, gyroscopes, fasteners, lock pins, guide pins, booms, antennas, doors, covers, screens, actuating mechanisms, gear trains, and mechanical restraining aids. It includes shipping containers, cradles, slings, dollies, tracks, and similar equipment which is specifically designed to transport and handle payloads during ground operations.

Mechanical hardware is an integral part of subsystems covered in this handbook. It can be piece parts of assemblies of flight systems as well as complete units.

Associated Hazards.- The prime hazards to be eliminated or controlled by the application of these guidelines are collision, contamination, explosion, illness or injury to the crew and loss of orbiter entry capability. Collision hazards can readily be generated if equipment is improperly located and insecurely attached to the payload structure. During launch, entry, or crashlanding conditions, components can break loose and become projectiles which can enter the crew compartment. Loose parts can collide with flight controls and can create injury potentials during extravehicular activities. Explosive hazards created by runaway or overspeeding rotary equipment should be eliminated by incorporation of protective devices. If material fractures occur, fragments should be contained by screens, guards, or covers to prevent damage or contamination of peripheral equipment and injuries to personnel. Telescoping booms and extending and retracting mechanisms must be designed with redundant retraction or a jettison capability to assure payload bay door closure in the event of mechanism malfunctions. Payload bay door closure is mandatory for orbiter entry capability. Industrial safety features should be considered in the design of ground handling equipment to prevent hazards to personnel.

Safe orbital payload operation and ground processing of payloads will depend on the selection of hazard-free hardware. In past manned programs, a number of hazards have been identified which are associated with the use of mechanical type hardware. The payload safety guidelines are based on this experience.

Suggestions are included for selection of fasteners, locks, guides, and shear pins used for the mechanical integrity of assembled components. Safety recommendations are listed for consideration in the design of extending and retracting devices, telescoping booms, and actuating mechanisms and ground handling equipment.

Since the mechanical subsystem overlaps in areas associated with structures, section 3.15, STRUCTURES, should also be reviewed.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.1 Design
	3.9.1.1 <u>Rotating Machinery</u>
Explosion	a. Pumps, compressors, turbines, centrifuges, and similar types of high speed rotating equipment should be provided with protective devices such as thermal overload sensors, bearing temperature sensors, pressure relief devices, vibration sensors, pump suction pressure interlocks, and overspeed controls to prevent bearing and material failures which could result in fragmentation.
Injury	b. High speed rotating components such as pumps, compressors, turbines, centrifuges, and gyroscopes should be shielded sufficiently to contain any wheel systems or failed parts. Rotating machinery should contain protective devices such as screens or covers to prevent accidental human contact with rotating members. Debris guards, screens, filters, and similar devices should be provided to contain potential floating objects in the zerogravity environment.
Injury	c. Where access to rotating members and operating equipment is necessary, power lockout and safety interlocks should be provided to prevent inadvertent operation.
Explosion	d. Pumps, compressors, turbines, fan blades, and similar rotating mechanisms should contain protective devices such as shear pins, friction clutches, magnetic clutches, or similar devices to protect the drive mechanism. Jammed rotating members can cause overheating , bearing, and material failures.
Contamination	e. In fluid systems, filters, strainers, and traps should be provided to contain residual debris which could threaten critical mechanical or electrical components. Debris or particle contamination from interfacing equipment can readily degrade critical mechanical items.
	3.9.1.2 <u>Gyroscopes</u>
Collision	a. Gyroscopes should include provisions for verification of rotational speed. Incorrect gyroscope rotational speed could result in erroneous or loss of payload attitude control. If occurring in a free flying payload, this problem could create a possible collision hazard.
Collision	b. Gyroscopes and accelerometers should be positively keyed to prevent interchanging or erroneous installation. Incorrect installation will result in erroneous attitude orientation on automated payloads which may lead to collision hazards.
Collision	c. When selecting gyroscopes for payload equipment, consideration should be given to their bearing temperatures, lubrication, and operational characteristics for the use environment.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.1.3 Fasteners
Injury	a. The torque value of bolts, connectors, and similar threaded fasteners should be specified in the design and should require the use of proper wrenching devices for assembly as opposed to using knurled knobs, wing nuts, etc. Properly torqued fasteners are essential to equipment operation.
Injury	b. The use of similar type mechanical fasteners for different applications close to each other should be avoided to prevent inadvertent interchanges of these fasteners (e.g., threaded fasteners of the same diameter and the same grip length but different shank length or those having the same shank length but different grip length). In assembly or service, interchanges of the fasteners can lead to operational failures creating hazardous conditions and endangering personnel safety.
Corrosion	c. The use of metal fasteners in contact with a dissimilar type metal should be avoided. If unavoidable, specify the protection of the fastener by barrier material such as sealant, tape, primer, or suitable coating. Dissimilar metals can create electrocouples and can lead to galvanic corrosion.
Contamination	d. The use of captive type fasteners, such as bolts or nuts, should be specified in the design to prevent dropping such items and damaging equipment (e.g., internal securing of electronic parts such as circuit boards).
Injury	e. The correct bolt lengths should be specified to avoid interference with piece parts which can lead to subsystem failures and create hazardous conditions to personnel.
Contamination	f. Self-tapping screws which generate metallic particles should not be used on electronic assemblies. Particles can cause electrical failures and contamination problems in the zerogravity environment.
Contamination	g. Calfax type fasteners should be considered for use in closing access panels in lieu of slotted or Phillips Screws. Such single force fasteners aid maintenance and reduce generation of metallic particles which can contaminate subsystem elements.
Injury	h. In the design of subsystem elements, standardized fasteners should be used to the maximum extent practical. This will tend to reduce maintenance downtime and will eliminate substitution of "like" type fasteners which can result in equipment failures and can intensify probability of hazards.
Injury	i. Access to mechanical fasteners should adhere to MSFC-STD-512 for both IVA (intravehicular activity) and EVA (extravehicular activity) operations.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.1.4 Lock, Guide, and Shear Pins
Injury	a. Black box designs should provide for use of guide pins or slide panels on drawers, and chassis subassemblies to align location of this equipment during installation. The guide pins and slides prevent contact of panels, chassis, or drawers with exposed equipment terminals and minimize connector failures, electrical malfunctions, etc.
Contamination	b. When pins are to be used, the design should include stowage location for the insertion of these locking pins or similar devices. If locking pins or similar devices, such as knobs, handles, caps, plugs, etc., are to be removed during flight operation, tether-like devices should be provided to hold these parts captive and prevent loose objects in the zerogravity environment.
Injury, Contamination	c. Friction-type locking pins or devices should not be used where the locking capability may be degraded as a result of repeated use (e.g., star washers and jam nuts should not be used).
Contamination	d. In the design of equipment which will require service and maintenance, associated washers or spacers installed with knobs, handles, locking pins, and similar devices should be adequately secured to prevent the unintentional removal of these parts with resultant floating objects in the zerogravity environment.
	3.9.1.5 Booms
Loss of Orbiter Entry Capability	a. In the design of booms which are to extend through airlocks, the locking and braking systems should not distort the boom when the clamping force is applied so that the boom cannot be retracted or ejected.
Collision	b.. Equipment which is mounted externally to the payload structure should be constrained so that under normal landing or crash load conditions, the equipment will not break loose, become a projectile and endanger the crew.
Collision	c. Payload or payload components which are to be deployed on extendible booms should be designed to withstand loads associated with deployment and flight operations. During on-orbit operations, the payload or payload components should not break loose and endanger the crew by possible equipment collisions.
Collision	d. The design of all the extension rod segments or extension mechanisms should contain safety latches or similar type devices to prevent ejection of equipment by inadvertent disconnections during the operations of extending the boom.
Loss of Orbiter Entry Capability	e. A jettison capability should be provided on solar array panels and extendible booms on automated (flyers) payloads which can be remotely controlled. Retrieved payloads must be stowed in the payload bay without payload bay door interference from extension booms.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.1.6 Doors, Covers, Windows
Injury	a. In the design of access doors, equipment covers, or hatches which are not to be removed, self-supporting features should be provided when they are to be opened during operational conditions to prevent hand injuries from unanticipated closures.
Contamination, Injury	b. Laser windows should be provided with covers to protect the window when not in use during flight and ground operations to prevent particle contamination leading to spurious laser reflections.
Injury	c. Payloads which will require direct interface with windows that form part of the pressure integrity of habitable areas of the STS should be designed to avoid any possible damage to the windows (i.e., scratches, cracks, etc.).
	3.9.1.7 Actuating Mechanisms
Collision	a. When designing and locating movable, actuating, or similar mechanical devices, adequate clearance should be provided to prevent (1) interference with structure; (2) puncture of fluid lines, valves, and tanks; and (3) contact with electrical wiring and components or other subsystem components. Mechanical stops should be provided to limit the motion at travel extremes to the maximum position for proper functioning of the actuated item preventing interference with interfacing equipment. The mechanical stops should be designed to absorb the impact resulting from actuating forces and inertia at the travel extremes.
Collision	b. Right-hand and left-hand parts should not be used in the design of actuating mechanisms. Similar mechanical parts and assemblies should be designed for interchangeability and reversibility. Those parts which are not interchangeable or reversible should be designed so that inadvertent interchange is not possible.
Collision	c. Rotational type mechanisms such as bell cranks and torque tubes should be designed to preclude incorrect installation on shafts (multiple keying is a preferred method). In routing torque tubes, structural deflection and its effect on tube functions should be considered.
Collision	d. Components which will require mechanical adjustments or alignment should be located where these adjustments can be made without excessive removals or disassembly of equipment. Adjustable mechanical devices should not be used where improper adjustment can lead to critical subsystem hazards.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.1.7 Actuating Mechanisms (continued)
Injury	e. The design of foldaway or foldover type latching mechanisms that must be in the folded position to assure positive locking should be spring loaded or pinned in the folded position to prevent inadvertent opening by vibration or shock under operating conditions. The foldout structure or mechanism should be designed and installed so that parts and wiring will not be damaged when the structure is opened or closed.
Injury	f. Locking or latching mechanisms should be designed to be operable by a single control and should provide a clear visual indication of whether the latch position is opened or closed. Positive indications of latching mechanisms are necessary to prevent crew injuries when these mechanisms are actuated.
Injury	g. Rotational equipment within enclosures requiring periodic access should be designed with positive manual loading devices. Equipment such as motor driven canisters containing photographic equipment or telescopes should have access door interlocks on the drive mechanism. Crew protection should be considered in film retrieval and component replacement activities.
Injury	h. The design of panels which will contain replaceable indicator lights should allow for replacement of the lights from the front of the panel to minimize injuries to maintenance and flight personnel.
	3.9.1.8 Mechanical Restraints
Injury	a. Restraining aids, such as handles, rails, and footholds, should be designed into large payloads for ease of movement of suited personnel during servicing, repair, or retrieval of equipment during EVA operations.
Injury	b. If an on-orbit maintenance requirement exists, design features should be included in mechanical elements to facilitate equipment failure detection, isolation, corrective action, and verification of repair. Allowances should be made for special tools, spares, maintenance equipment, and the required space for orbit operations. Accessibility to equipment attachment, electrical connections, and equipment plumbing will be necessary. On-orbit maintenance features should be designed to assist a suited crew member to perform the needed corrective action.
	3.9.1.9 Antennas
Injury	a. Antennas which are designed with electromechanical drive mechanisms to permit scanning should include a positive locking device to prevent the antennas from inadvertent rotation and personnel contact during flight or ground operations.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.1.9 Antennas (continued)
Collision	b. To prevent rotating antennas from contacting adjacent subsystem equipment, the required antenna envelope should be specified in interface documents and on interface drawings. Interface drawings should also specify the look angles of signal detectors, sensors, and transducers which may be shadowed by a rotating antenna.
Loss of Orbiter Entry Capability	c. As an additional safety measure in the design of extendable antennas, methods should be considered for manual disconnection in the cargo bay by an EVA crewman.
	3.9.2 Flight Operations
	None
	3.9.3 Ground Operations
	3.9.3.1 Transportation
Collision	a. Vehicles designed to transport equipment should contain permanently attached safety chains capable of holding the vehicle if the towbar or hitch attachment fails. Hinge-type towbars should have positive locking devices for stowage in the raised position with stops to prevent contact or collision with the load on the vehicles.
Collision, Injury	b. Transportation devices should have tiedown provisions for positive servicing of equipment. The devices should contain reusable placards showing load limits. The tiedown devices should be provided with positive locking devices including tension and torque values on visible placards to prevent damage to the equipment and impact hazards to ground handling personnel. Attach points for the tiedowns should be clearly marked to avoid possible confusion in the use of the equipment. "No-step" marking should be included as needed on payload equipment installed in transportation devices to prevent injury to ground personnel.
Collision, Injury	c. Casters used on transportation devices should have self-contained wheel locking devices to avoid slipping or runaway creating collision hazards with ground personnel or damage to peripheral equipment.
Collision	d. Braking and wheel locking device controls on towed transportation equipment should be protected against inadvertent operation.
Injury	e. The design of shipping containers should permit the safe packing and unpacking of equipment without functional damage to any specially-built containers, fixtures, or equipment from handling or static electrical discharge. Materials used for packing should be nonflammable commensurate with the container's use and exposure.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.3.1 Transportation (continued)
Injury	f. Cradles or support devices should be designed to support the equipment adequately and to conform to the shape, size, and contour of the payload. The cradle and support devices should be designed with tiedown attachments for securing the payload equipment to prevent slipping and dropping. The cradles and support devices should also have tiedown provisions for securing the cradles or support devices to the transporting equipment. Hoist points should be readily visible on the cradles or supporting devices.
Injury	g. Load bearing surfaces of the cradles or support devices should have sufficient bearing area to support the equipment and padding to protect the equipment from damage. The center of gravity of these devices should be conspicuously identified. Grounding provisions should be provided and utilized to bleed off any accumulated charge.
Injury	h. The design of shipping containers should allow for payload cargo removal in a vertical direction to minimize dropping equipment hazards. The handling and lifting (removal of payloads from containers) should be included in program reviews to assure proper handling at launch facilities.
Injury	i. Practical design features should be included to facilitate safe handling of bulky items during installation, maintenance, or replacement. These should include handles, lifting lugs or eyes, tapped holes for attachments, etc. (It should be remembered that flight items may have to be put into shipping containers, humidity control bags, etc., for replacement, rework, etc.)
Explosion	j. Special payload dollies, trucks, and transporters which contain internal combustion engines and are to be operated in propellant transfer areas should be equipped with spark arrestors and carburetor flame arrestors (authorized air cleaners) to prevent introducing ignition sources. (Vehicles containing catalytic converters will be excluded from operating in spacecraft use areas.)
Collision	k. Special payload trucks or dollies used for moving sensitive equipment, such as guidance and pyrotechnics, should be provided with shock mounts, dessicants, and other protective devices to prevent damage to critical parts whose failures during orbital operations can introduce hazards to crew personnel.
Injury	l. Payload suppliers furnishing ground handling equipment should provide procedures and historical record files for periodic proof load testing data. The following information should be included in the file. (1) Drawing number and part number of the device. (2) Manufacturer.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.3.1 Transportation (continued)
	(3) Fabrication date.
	(4) Date of last proof load test.
	(5) Date of rework or repair.
	(6) Date of magnaflux, X-ray, or penetrant dye check.
	(7) Quality control verification inspection.
	(8) Maximum safe working load.
	Payload equipment used and proof tested at other than the supplier's facility may be used without further proof tests if test documentation is available; if records show that proof testing meets minimum conditions; and if inspection of the equipment shows no damage or deterioration.
	3.9.3.2 Test and Checkout
Injury	a. Payload equipment which must be ground tested and can expose personnel to surface temperatures above the threshold of pain (125°F) (52°C) or in the range of cryogens should be provided with adequate ground handling fixtures to prevent inadvertent contact by personnel.
Injury	b. Components or mechanisms which will require operations or adjustments during ground operations should be designed to accommodate the personnel who will be responsible for performing these functions. All controls which should not be operated during ground operations should be marked with clearly visible placards or labels.
Injury	c. Payload equipment which is to be hand-carried should not exceed 45 kg (100 lb) mass provided the center of mass is within 35 cm (14 in) of the handhold. Equipment exceeding these limits should be transported on ground handling equipment.
Injury	d. Payloads containing pressurized fluids or gas in containers in which a rupture could result in uncontrolled motion of the experiment or can release toxic fumes requiring immediate evacuation of the area should not be hand-carried. Handling equipment containing handles, lids, and covers should be provided for hazardous materials. Easy to recognize markings should identify contents, state antidote information, or special handling instructions.
Injury	e. Equipment to be serviced, maintained, and repaired by component replacement should be designed for ease of access without requiring the removal of other equipment, wire bundles, and fluid lines. Components should be designed with features that contribute to the ease and rapidity of maintenance.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.3.2 Test and Checkout (continued)
Contamination	f. Nozzles and vents should be protected by readily visible covers or protective inserts to prevent entrance of moisture, debris, or other contaminants prior to launch.
Fire	g. Protective covers designed for the protection of flight equipment should offer maximum practical protection against fire.
	3.9.3.3 Assembly, Installation, Service
Injury	a. Payload equipment requiring blankets as thermal controls in high traffic areas of the payload bay should be designed for easy installation and removal.
Collision	b. Mechanical locking features should be provided on lifting devices to prevent inadvertent lowering of the equipment if the lifting mechanism fails.
Injury	c. To minimize equipment damage and potential injury hazards to personnel in handling payload equipment, fixtures, cradles, or similar devices should be provided as needed.
Injury	d. Readily visible and tethered connector caps, plugs, or covers should be provided as protection against damage and contamination at electrical and fluid outlets.
Collision	e. The design of sling cables for use on payloads should be of sufficient length so that the angle formed by the cables at the point of the attachment to the lifting device should not exceed 45 degrees.
Injury	f. The design specifications of payloads should include location of lift points, attach points, center of gravity, and gross weight for which lifting, hoisting, or handling fixtures may be required.
Injury	g. Payload equipment which will require lifting or moving during ground operations should contain temporary or permanent installation of attach points, lifting eyes, tiedowns, and similar hardware for positive attachment of slings, cable locks, and similar devices. If cradles or support devices are used, they should have provisions for lifting equipment (e.g., sling eyes).
Injury	h. All platforms, handrails, booms, boom extension devices, and similar installations which are not designed for use in a one gravity environment should contain placards with ground operating load limits. Adequate protection must be provided during ground handling to prevent damage to these devices and resultant malfunctions during operating conditions.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.9 SUBSYSTEM MECHANICAL

ASSOCIATED HAZARD	GUIDELINES
	3.9.3.3 Assembly, Installation, Service (continued)
Injury	i. All work stands should have adequate railings around their platforms. If these stands are mounted on casters, some positive means of locking these or transferring the load to separate support pads must be provided and utilized.
Injury	j. Slings, handling fixtures, and other support equipment requiring periodic proof load testing should have some means of assuring that pins, devices, cables, etc., that may readily be disassembled cannot be inadvertently changed out with similar pieces that were not part of the whole assembly when it was last proof tested.

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OPTICAL GUIDELINES

3.10 OPTICAL

System Description.- Optical instruments will comprise a high percentage of the payloads carried by the STS. These instruments are of two types: data gathering and data transmitting. These data are limited to light which will pass through a lens or will reflect from a first surface grating or mirror. Such light ranges from 100 angstroms for extreme ultraviolet to 300 microns for infrared depending on intensity of the light and the density of the media in the path of the beam. The optical elements are generally metal or glass and are either transmissive or reflective. Typical optical components include first surface mirrors and gratings (flat, parabolic or concentric), lenses (concave or convex), flats and beam splitters (coated and uncoated), and prisms (coated and uncoated). Other devices and components related to optical instruments are apertures, slits, fiducials, baffles, light tubes, covers, and doors. Data may be obtained electronically, photographically, or visually.

Typical interfaces with optical instruments are visual, mechanical, electrical, and spatial. Few systems will use direct viewing for data retrieval. If a crewman is required or able to view potentially hazardous intensities and wavelengths, however, these guidelines should be utilized. Ground support interfaces include optical, electronic and radiation from sources such as lasers, mercury vapor discharge tubes, carbon arc sources, etc., for sensor excitation, calibration or alignment.

Associated Hazards.- The potential hazards which must be considered in design, handling, and operations of optical equipment and associated energy sources may be grouped into four general categories defined as follows:

1. Personnel exposure to dangerous light radiation. High power and focused low power lasers can cause lesions of the skin. Most lasers can damage the eye to some extent, and reflected laser energy in some cases is sufficient to do serious eye damage. There are lasers that operate in UV (ultraviolet) and IR (infrared) wavelengths besides the visible wavelengths. These two categories are especially hazardous as their beams and reflections are invisible regardless of the energy level. Certain CO_2 lasers, operating in IR, are capable of extreme beam temperatures and will ignite some target materials.

Other dangerous sources of light radiation are mercury vapor lamps, high intensity carbon arc, and solar radiation. Solar radiation at ground level ranges from about 2800 angstroms for UV to about 300 microns for IR due to the atmospheric cutoff. This atmospheric cutoff is due in a large part to the ozone layer (40,000 to 100,000 feet) (12,000 to 30,000 meters) which filters much of the sun's dangerous radiation. This filtering process will not exist during on-orbit operations and solar radiation through a spacelab mounted quartz window may be as low as 1850 angstroms which is hazardous to personnel.

The primary hazard concerning carbon arc and mercury vapor lamps is eye damage from sustained observation of these light sources. A carbon arc is very uncomfortable to look at because of its extreme intensity. A mercury lamp, however, is relatively dim. This is deceiving and individuals have sustained partial loss of vision from looking at these sources for a sustained period of time.

2. Temperature extremes causing toxic fumes. High temperatures involved with the various light radiation sources can cause toxic outgassing or combustion byproducts. Certain paints, when heated by radiation sources, give off toxic gases even though they may be acceptable for flight use at ambient temperature and pressure. Laser welding or material testing can result in toxic fumes which could be hazardous to the crew in a self-contained environment such as the STS.

3. Injury due to shatterable materials. Optical systems contain many elements made of shatterable materials such as lenses, gratings, filters, mirrors, prisms, flats, beam- splitters, image dissector tubes, photo-multiplier tubes and quartz envelopes. Such shatterable materials are potential hazards to crewmen if they ingest the broken particles. Everything possible should be done to prevent such an occurrence without altering the abilities of these instruments to take data of the quality and wavelengths they are required to do.

4. Contamination from gases and cryogenics. Contamination of habitable areas is a hazard associated with many light radiation sources coupled with optical systems. Gases associated with some types of laser are bromine, chlorine, hydrogen cyanide and others. These should be eliminated from the habitable environment, or they could present toxic threats to operating personnel. Cryogens necessary for light source cooling should be carefully handled to prevent "burns." Liquid hydrogen must be properly vented to prevent a possible fire hazard. Mercury vapor lamps, if shattered or leaking, could introduce toxic mercury into the environment. Personnel working around UV light sources, such as mercury vapor lamps without adequate protection, may suffer skin burns, and UV retinal damage to the eyes.

The following guidelines are provided to avoid such hazards in the design and operation of optical payloads.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.10 SUBSYSTEM OPTICAL

ASSOCIATED HAZARD	GUIDELINES
	3.10.1 Design
	3.10.1.1 General
Injury, Radiation	a. Unfiltered grating systems for UV, IR, or visible light application all have a zero order which contains all wavelengths which the grating sees. Thus, the zero order will have from about 2800 angstroms to about 20 microns when in direct sunlight at sea level. The same zero order could contain as low as 1850 angstroms in a man-made environment such as from a mercury vapor lamp onboard the spacelab or in any laboratory at close range to the light source. Optical instruments should be designed to trap this beam so that it cannot be viewed by operating personnel.
Injury, Radiation	b. Quartz windows, apertures, or envelopes should not be used with dangerous wavelengths unless suitable measures are taken to protect personnel from UV and/or IR burns.
Injury, Radiation	c. High energy laser systems, pulsed or otherwise, should not be used with optical experiments unless interlocks are provided to prevent all laser light, even reflections, from escaping the experiment housing and viewed or otherwise contacted by personnel. Under certain conditions, such laser systems can cause blindness and lesions of the skin (see paragraph 3.10.1.2, Lasers.)
Injury, Radiation	d. Light intensities and spectral wavelengths at the eyepiece of direct viewing optical systems should be limited to a safe range to avoid damage to the eye.
Injury, Radiation	e. In the design of direct viewing telescopes, consideration should be given to automatic means to protect the viewer's eyes if the field of view is inadvertently exposed to direct or reflected sunlight.
Injury, Radiation, Temperature Extremes	f. In the design of optical systems which require crew viewing consideration should be given to incorporating baffles and interlocks to preclude inadvertent exposure to focused energy of a damaging or hazardous nature.
Injury	g. Enough space should be provided at the viewing end of a telescope so that the operator has free egress with the telescope locked in any position.
Contamination, Implosion, Illness/Injury	h. Glass and similar shatterable material should be covered or encapsulated with a solid transparent material to protect against particles being introduced into the spacecraft habitable environment as a result of breakage. Where this is not possible or practical, other remedial measures should be taken such as the use of removable protective covers, warning signs, etc.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.10 SUBSYSTEM OPTICAL

ASSOCIATED HAZARD	GUIDELINES
	3.10.1.2 Lasers
Injury, Radiation, Fire, Temperature Extremes	a. Limit stops, interlocks, and shields should be provided to ensure that a laser beam cannot be misdirected toward personnel, adjacent equipment, or structure.
Injury, Radiation, Fire, Temperature Extremes	b. Power lockouts or interrupter devices should be provided on laser devices to protect flight personnel during maintenance or EVA operations.
Injury, Radiation, Fire, Temperature Extremes	c. Power interruption capability should be provided whenever a laser is removed from its mount.
Temperature Extremes	d. Positive locking features should be provided on all laser reflectors to preclude focus changes due to vibration (such as during launch) or by inadvertent contact during maintenance or general EVA operations.
Electrical Shock	e. Lasers should be designed and constructed so that all external parts, surfaces, and shields are at ground potential at all times.
Explosion, Injury	f. Laser systems should use only those materials which can withstand the stresses caused by repetitive pulsing of flashlamps for long periods.
Radiation, Temperature Extremes, Injury/Illness	g. Laser reflector mirrors should safely withstand the thermal stresses of reflecting the laser beam. It is recommended that external mirrors be covered when not in use to keep them clean and thus minimize thermal absorption rates.
Injury, Radiation, Electrical Shock	h. The use of quartz is not recommended for flash tubes. If required, however, a suitable shield of plastic or nonshatterable glass should be used to absorb the undesirable UV radiation. Such tubes should be disabled when the cavity is open for maintenance.
Fire, Injury, Radiation, Temperature Extremes	i. A shutter system should be included to prevent the laser from being fired inadvertently.
Fire, Injury, Radiation, Temperature Extremes	j. Provisions should be made so that power output measurements can be made with the beam totally enclosed to prevent specular reflections which could be hazardous to the viewer or could even ignite combustibles at certain wavelengths.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.10 SUBSYSTEM OPTICAL

ASSOCIATED HAZARD	GUIDELINES
	3.10.1.2 Lasers (continued)
Fire, Injury, Radiation, Temperature Extremes	k. Laser systems should be designed to enable as many adjustments and system checks as possible to be made without the laser transmitting to reduce the radiation hazard potential to personnel.
Explosion, Radiation, Temperature Extremes	l. Laser optical systems should be environmentally sealed whenever possible to prevent moisture buildup in the path of the beam. Spurious reflections, heat buildup, steam and misdirection of the laser beam could result.
Explosion, Temperature Extremes	m. Optical coatings of the hardest practical material should be used with laser systems. Internal reflections caused by degraded coatings can cause heating and possible melting of the lens surface. These conditions can cause multiple hazards.
Corrosion, Temperature Extremes	n. Laser systems should be designed so that no field adjustments or maintenance are required that would expose optics to contamination when power levels are such that contamination could cause potential hazards.
Injury, Radiation	o. Laser systems should be designed so that during boresighting or power measurement operations the laser beam is totally enclosed and inaccessible to the eye.
Injury	p. Laser sighting eyepieces should be fitted with filters for the wavelength at which the laser is operating.
Explosion, Injury, Temperature Extremes	q. There should be ample capacity in laser operating subsystem elements such as power handling capacity of storage capacitors or cooling capacities of mirrors.
Temperature Extremes, Injury/Illness	r. Mirrors in high powered laser systems should be designed first surface to prevent spurious reflections and to reduce heat absorption.
Injury, Radiation	s. Laser power supplies with 15,000 volts and above should be marked to show the amount of X-radiation and microwave radiation generated when shields are removed.
Corrosion, Explosion, Injury	t. Handling of quartz flash tubes can result in catastrophic failure during operation. Fingerprints can etch the quartz which can cause the tube to crack and/or explode.
Contamination, Fire, Radiation, Temperature Extremes	u. A laser beam should be terminated with target material that is nonreflective at the laser wavelength, is fire resistant, and does not emit toxic fumes when vaporized. The area around the target and the beam path should be free from reflective materials as well.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.10 SUBSYSTEM OPTICAL

ASSOCIATED HAZARD	GUIDELINES
	3.10.1.2 Lasers (continued)
Fire, Injury, Radiation, Temperature Extremes	v. Alignment of target, optics, filters, etc. should be accomplished with low powered lasers such as helium-neon.
Injury, Radiation	w. When necessary to view the target or beam while a laser is energized, it should be viewed through a closed circuit television or an optical comparator with appropriate filter.
Contamination, Fire, Injury, Radiation, Temperature Extremes	x. Because of their higher power output (megawatt and gigawatt range), solid state lasers such as ruby-pulsed devices should be operated by remote control firing where feasible. Television monitoring eliminates the requirement for personnel to be in the proximity with the laser. An alternative is to enclose the laser and beam with a light-tight box.
Explosion, Fire, Contamination, Temperature Extremes	y. Since damage to materials from laser energy is caused by direct radiative heating and resonance conditions at wavelengths equal to absorption lines of the materials, the ignition temperature and absorption bands are necessary parameters in selecting a safe target material.
Fire, Injury, Radiation, Temperature Extremes	z. The unused secondary laser beam emerging from the rear aperture of a laser should be capped. Likewise, the unused beam resulting from use of beam splitters should be terminated. When using optical gratings with lasers the zero order, blazed order, and several orders above and below the blazed order can have dangerous beam intensities radiating around the Rowland circle. These should be blocked from view of operating personnel.
Contamination, Fire, Injury, Radiation, Temperature Extremes	aa. Safety provisions such as interlocks at the entrance of the laser facility should be installed and constructed so that unauthorized or transient personnel are denied access to the facility while the laser power supply is charged and capable of firing.
Contamination, Fire, Radiation, Injury, Temperature Extremes	bb. Higher-power (watt range) IR lasers such as the CO_2 laser (10 micron wavelength) should be used with the utmost precaution because of an invisible beam and the associated fire hazard. A sufficient thickness of material suitable for terminating the laser beam should be provided as a backstop for the beam.
Fire, Injury, Radiation, Temperature Extremes	cc. Reflections of the IR beam should be attenuated by enclosure of the beam and target area or alternatively by eyewear constructed of a material opaque to the CO_2 wavelength, such as Plexiglas.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.10 SUBSYSTEM OPTICAL

ASSOCIATED HAZARD	GUIDELINES
	3.10.1.2 Lasers (continued)
Contamination, Fire, Explosion, Injury	dd. Laser installations should incorporate adequate means to prevent the accumulation of hazardous gases where continuous-flow gas lasers are used. Accumulation of cryogen liquids and gases should be controlled within the means of the ventilation system where purging and cooling of lasers is required. Use of these liquids may result in the formation of liquid oxygen. This can become an explosion or fire hazard. (See section 3.3, CRYOGENICS.)
Injury, Radiation	ee. Caution should be taken when operating lasers of subthreshold intensities. Current safety criteria assume that laser damage occurs on an all-or-none basis. Recent research by Lt.Col. G. L. M. Gibson, U. S. Air Force School of Aerospace Medicine has proven that single subthreshold exposures which are less than half of a threshold dose are cumulative and therefore each subthreshold exposure must damage, or in some manner increase, the retinal susceptibility to subsequent exposures.
	3.10.2 Flight Operations
Fire, Injury/ Illness	Laser experiments involving potentially dangerous heat sources or toxic materials should be performed in areas where personnel access can be limited, and where adequate ventilation and fire protection are provided.
	3.10.3 Ground Operations
Radiation, Injury	a. Most gas discharge tubes are made of quartz. Care should be exercised in using these, especially mercury vapor, as UV down to about 1850 angstroms is possible. Eye and skin protection should be utilized.
Injury, Radiation, Temperature Extremes	b. Suitable safety measures should be taken when operating discharge tubes which require microwave cavities and corner reflectors. (See section 3.14, RADIATION.)

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PRESSURE SYSTEMS GUIDELINES

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3.11 PRESSURE SYSTEMS

System Description.- Payload pressure systems consist of pressure vessels, lines and hoses, support members, connections, valves, regulators, filters, seals, instrumentation, and all other hardware containing liquids or gases under pressure greater than ambient. The fluids and gases may be inert or chemically active and may be used over a wide range of temperatures. Special considerations for unique fluid and gas systems such as cryogenics, propulsion, hydraulics, and environmental controls are covered separately in this document under their respectively titled guideline sections.

Like similar STS pressure systems, payload pressurized gas or fluid systems will be normally located away from inhabited areas. Where practical, they should also be separated from each other and from critical payloads or orbiter systems. Shields or structures should be used as added precautions against sympathetic explosion, fire propagation, or damage due to schrapnel. Payload pressure systems will generally be subjected to the same flight environments as similar STS hardware. These systems should withstand, without damage or failure, the loads induced by STS vibration and accelerations at the temperatures and pressures that will be experienced in the STS environment.

Special attention must be given to the design and test of pressure vessels and related control devices to prevent the possibility of explosion. For example, each pressure vessel should satisfactorily meet the requirements of NSS/HP-1740.1 "Aerospace Pressure Vessel Fracture Control," and JSC 07700, Volume XIV, "Space Shuttle Payload Accommodations" to accommodate the most severe combination of environmental and pressure conditions expected in use. Fracture mechanics analysis is performed on aerospace pressure vessels to determine flaw growth, stress corrosion, failure modes and other characteristics of materials used for pressure vessels. Each type pressure vessel should successfully pass qualification tests to demonstrate compliance with design requirements. Each pressure vessel accepted for operational use must also pass acceptance tests to prove its flight acceptability.

Associated Hazards.- The primary hazard associated with pressure systems is explosion. Risk of explosion will depend on system variables such as pressure, volume, materials, wall thickness, shelf life, and environment. The degree of hazard to be controlled under any particular set of conditions is generally proportional to the system pressure and volume of pressure vessels. For example, a low pressure high volume pressure system may contain as much explosive energy as a high pressure low volume system. The results of a pressure system explosion include fire; crew or equipment contamination due to release of toxic or corrosive fluids and gases; and crew injury or equipment damage from high velocity flying fragments or blast overpressure.

Pressure systems need not explode to be hazardous. A tank or line rupture, a failed connector or flex hose, or a broken seal could allow the leakage of toxic, corrosive, or flammable materials into occupied areas resulting in potential fire or contamination hazards. Rupture of a length of tubing or flex hose could result in a violent whipping action of the item and could damage adjacent equipment or structure.

Fire, contamination, explosion, and other hazards can also be caused by the improper selection, location, setting, and shielding of pressure system control devices. For example, pressure regulators can fail open because of excessive vibration; relief valves can fail to open when necessary to protect a pressure vessel; a vent valve may be designed to allow corrosive gas to impinge on sensitive equipment, and may create sufficient thrust to disrupt stability control of a deployed payload or even the STS.

The following guidelines cover the various pressure system elements which may cause or be affected by these hazards and discuss the criteria for safe operation of fluid or gas systems.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1 Design
	3.11.1.1 <u>General</u>
Explosion, Contamination, Illness/Injury, Collision	a. The designation of pressure levels can vary between low (0-500 psi) (0-35 kg/cm^2), medium (501-3000 psi) (35.2-210.9 kg/cm^2), high (3001-10,000 psi) (211-703.1 kg/cm^2), and ultra high (above 10,000 psi) (703.1 kg/cm^2). Extreme care should be exercised in the design and operation of all pressure systems to minimize the potential hazard of leakage, component rupture, or explosive disintegration with accompanying shock waves and fragmentation. The primary method for controlling pressure system hazards is by "design to contain."
Explosion, Contamination, Injury/Illness, Collision	b. The design of pressure systems should include the capability of returning the system to a safe condition at anytime during ground or flight operations if an equipment failure or malfunction or a procedural error occurs. Methods for accomplishing this could include:
	(1) Provisions to bleed or vent the subsystem as protection against overpressure rupturing or bursting of system elements.
	(2) Provisions for isolating portions of the system to preclude shutdown of the entire system.
Explosion, Contamination, Injury/Illness	c. If at all possible, pressure systems should be located outside inhabited areas of the shuttle vehicle. Also, they should not be located in proximity to other sources of high energy such as heat, power, and pressure unless adequate shielding has been provided.
Explosion, Contamination	d. Payload pressure systems should withstand all shuttle initiated structural loads, acceleration, shock, or other loads while under operating pressure conditions and maximum operating temperature without suffering permanent set, stress damage or leakage. A complete structural analysis should therefore be conducted on all high pressure systems. This would include the worst-case consideration of vibration induced stress, surge and shock stress, acceleration loading, and thermal degradation of strength, as applicable.
Collision, Loss of Entry Capability	e. Nonpropulsive venting of fluids and gases has been incorporated on previous manned space programs and is also to be accomplished on the shuttle program. The payload designer should also strive to provide nonpropulsive venting and pressure relief, because significant unvented thrust can be generated at the open end of small lines, even under low pressure. For example, a 1-inch (2.54 cm) line charged to 200 psi (14 kg/cm^2) can develop approximately 180 pounds (82 kg) of thrust.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.1 General (continued)
Explosion, Contamination	f. Pumps, valves, regulators, lines and hoses, and all such prefabricated components of a pressure system should have an authenticated pressure and service rating equal to or greater than the maximum allowable pressure for those components.
Contamination	g. To minimize leakage and possible overstress conditions, pressure system lines and component joints should be of welded or brazed construction. Solder joints are more susceptible to leakage and should be avoided.
Fire, Explosion	h. Dissimilar metals should not be used in coolant system components if a galvanic circuit is thereby established with the coolant acting as the electrolyte.
Explosion, Collision	i. Design provisions should be made to relieve atmospheric pressure from payloads so that during the mission ascent phase there will be no possibility of pressurization beyond structural limits of the payload. Conversely, during the mission descent phase, payloads should also be provided the capability to relieve vacuum conditions because of outside ambient pressure.
Explosion, Contamination	j. Shock waves can be generated within a pressure system because of sudden changes in gas flow. Those shock waves can generate pressure spikes far in excess of the system's design operating limits. Sudden changes in valve settings, rapid directional changes, or close-ended T-joints should be avoided in the design of pressure system components.
Fire, Explosion	k. Pressure systems for oxidizers and fuels and other safety critical pressurizing systems should be free from dirt, lubricants, metallic debris, and organic matter which may combine with the propellants to cause fire or explosion.
Explosion, Contamination, Injury/Illness	l. Accurate sensors should be incorporated to ensure that the pressure is totally relieved prior to opening the system for maintenance, replacement, checkout, or other reasons. Opening a pressure system prior to total depressurization could create a hazard to personnel or equipment in the vicinity. It could also damage equipment from explosive decompression.
	3.11.1.2 Pressure Vessels
Collision, Explosion, Fire	a. Payload pressure vessel structural retention devices/ brackets should be capable of withstanding the 9 g crash load limit established for orbiter structure. Failure of pressure vessel retention mechanisms could result in failure which may be catastrophic to the shuttle and its crew at this critical time.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.2 <u>Pressure Vessels</u> (continued)
Explosion, Collision, Fire	b. It is highly desirable that all pressure vessels be designed so that failure due to overpressure or to material properties will not produce shrapnel. Methods to minimize this hazard include: (1) Use of appropriate safety factors in tank design. (2) Use of fiberglass wound tanks. (3) Use of pressure relief devices to eliminate overpressure conditions. (4) Use of fracture mechanics analyses for each pressure vessel material used and application desired. (5) Reduction of stress concentration as a factor in tank design. (6) Assurance that fabrication materials of a pressure vessel are metallurgically compatible with the contents. (7) Qualification tests to verify design of a particular pressure vessel and acceptance testing to identify random manufacturing defects. (8) Use of shrapnel proof barriers or remotely located tank installation points to prevent propagation of an explosion from one tank to another and to protect the orbiter crew and other critical equipment. (9) It is recommended that the requirements of NSS/HP-1740.1, "Aerospace Pressure Vessel Fracture Control," be satisfied for the design, test, and operation of lightweight metallic pressure vessels and systems.
Explosion, Contamination, Fire, Collision	c. Pressure vessels should normally be installed outside the STS manned or pressurized compartments to protect the crew and the pressure integrity of the compartment. Small pressure vessels may be permitted inside the pressurized compartment (cabin) provided they do not have credible failure modes and their failures will not expose the crew or vehicle to hazards.
Contamination	d. Double containment is highly recommended whenever toxic, flammable, or corrosive fluid can create an immediate hazard if inadvertently released into a habitable area. Venting if provided should be to space or to another onboard container.
Contamination, Fire	e. Pressure vessels should be protected against failure by implosion as a result of inadequate inflow of ullage gas or pressurants as the tank content is drained. Protective devices would include the use of pressure relief valves and special procedures for prevention of tank draining without acceptable inflow of ullage gas.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.2 Pressure Vessels (continued)
Explosion, Collision	f. The location of pressure vessels within an assembly or as installed on the shuttle must consider the possibility of tank failure caused by impact with adjacent hardware. Tank mounting designs should allow for structural distortions due to internal pressure, aerodynamic forces, vibration, and sustained acceleration loading.
Collision, Loss of Entry Capability	g. Pressurized gas vessels must be firmly secured by their mounting brackets to prevent a vessel from becoming a projectile from the thrust of the contained gas if a line or connector failure occurs.
Contamination, Fire, Explosion	h. The structural stability of a pressure vessel or its surrounding payload structure should not be dependent on the tank's being pressurized. If tank structural stability is independent of tank pressurization, then safety will be enhanced by:
	(1) Precluding the necessity for transporting, testing, and installing the payload (tank) in its pressurized mode.
	(2) Allowing tank pressurization at the latest time possible in launch preparation.
	(3) Eliminating the possibility of tank collapse by accidental depressurization.
	(4) Dumping of tank contents under abort conditions and landing loads without collapsing the tank. (Emergency landing with a pressure vessel fully tanked and pressurized is undesirable.)
Contamination	i. Pressure vessels and reservoirs should have isolation shutoff valves installed as close as possible to the downstream exit of the pressure vessel but below the pressure relief device if one is used.
Contamination	j. Provisions should be made to drain liquid from pressure vessels to enhance safety during maintenance or replacement of components.
Explosion	k. Pressurized gases should be isolated from heat sources, be cooled by refrigeration, or be insulated to prevent excessive pressure buildup.
Explosion, Collision, Fire	l. Pressure vessels should be clearly marked or labeled to identify operating pressure, type of content, and capacity.
Loss of Entry Capability	m. The gaseous quantity capacity of pressure vessels should be limited or a flow restrictor added so that a failure causing rapid expansion into the orbiter cargo bay will not result in overpressurization of the bay. This would be a concern only when the cargo bay doors are closed (i.e., during launch preparation, launch, entry, and landing phases).

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.2 Pressure Vessels (continued)
Explosion, Loss of Entry Capability	n. Each pressurized gas source or line within a manned compartment (spacelab, orbiter cabin), which could release gas into the compartment at a greater rate than the compartment pressure relief and vent system can discharge it, should have a flow restriction device at the pressure source to reduce the flow of gas to a level which can be handled by the manned compartment relief system.
Explosion, Fire, Loss of Entry Capability	o. Venting of inert or nonhazardous gases into the orbiter payload bay should be minimized at all times but should be further restricted during periods when the payload bay doors are closed (i.e., during prelaunch, launch, entry, and landing phases).
Fire, Collision, Contamination	p. Hazardous gases or liquids (toxic, corrosive, flammable, radioactive) should not be vented into the payload bay. Safety should be achieved by "design to contain."
Collision, Fire	q. Payload vents should not be propulsive. The location of vent ports should be located away from hot spots and should not impinge on any surface which may be sensitive to the venting material.
	3.11.1.3 Lines, Tubing, and Hoses
Contamination, Fire, Injury/Illness	a. It is important that all pressure lines (fixed or flexible) be properly clamped and supported to minimize flexing, chafing, abrasion, and strain which could lead to line leakage or rupture and to restrain the line if rupture does occur. The following criteria for clamping and supporting pressure lines or hoses should be considered for applicability to individual designs: (1) System components should be supported by firm structure rather than by connecting tubing. (2) All lines used in fixed applications should be independently clamped or supported. (3) Clamps and supports should not restrict thermal expansion and contraction of the lines and should protect against damage from mechanical stress and vibration.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.3 <u>Lines, Tubing, and Hoses</u>
	(4) All rigid lines should be supported as close as possible to each bend in the line.
	(5) Flexible hoses should have a maximum slack allowance of 5 percent of the total length.
	(6) Flexible hoses should have hose restraints connected across the hose connections and should be secured to the structural members.
	(7) Flexible hose restraints should be at least 50 percent stronger than the calculated impact force on an open line (under maximum operating pressure) moving through the flexure distance of the restraint.
	(8) A protective coating should be provided as an integral part of each flexible hose to preclude damage from abrasion or chafing.
	(9) Welds and wall thicknesses should be verified for requirement compliance by nondestructive tests.
Contamination, Fire, Injury	b. When routing pressure lines, the following safety considerations should be observed:
	(1) High pressure lines should not be routed through manned compartments. If this is unavoidable, a shutoff valve should be located in the line immediatley after it enters the compartment.
	(2) Where redundant fluid or gas lines are used, the redundant line should be separated as far as practical from the primary line.
	(3) Vent lines and pressure relief lines should be located so that escaping gas or liquid will not be hazardous to personnel or other equipment.
	(4) Fluid lines should be protected from freezing because of proximity to cryogenics or exposure to space. A thermostatically controlled heater is one method of protecting fluid lines from clogging.
	(5) Plumbing lines should not be routed over sensitive equipment to protect this equipment from leaks or condensed moisture during ground operations.
	(6) Locations of service points for filling, draining, purging, or bleeding pressure systems during ground operations should be external to the shuttle vehicle where practical and when the system contents constitute a hazard.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.3 Lines, Tubing, and Hoses (continued)
Injury, Contamination	c. Pressure lines and flexible hoses should be shielded, located or otherwise protected to preclude use as hand-holds or foot-holds during ground or flight operations.
Contamination	d. It is usually advantageous from design, weight, and safety standpoints to use rigid type tubing in all applications except when vibration, relative motion, contraction, or expansion properties are unusually severe. Only in such cases should flexible hose construction be considered.
Injury, Explosion	e. All lines, including flexible hoses, should be clearly marked or coded to identify content, capacity, operating pressure, direction of flow, date of last proof test, and the required retest interval.
Contamination	f. In the design of flex hose routing, sharp bends or twists should be avoided. A minimum of five times the outside diameter of the hose is considered acceptable as a bend radius.
Explosion, Contamination, Fire, Injury	g. In a complex plumbing installation, it is sometimes difficult for fabrication, assembly, and test personnel to know the direction of flow. It is, therefore, important to eliminate installation errors of fluid line components whose function is dependent on direction of flow. To minimize this possibility, the following design safety features should be considered. (1) When feasible, the design of direction sensitive fluid line components should incorporate end fittings or connections whose dimensions or configurations will not permit incorrect assembly/installation. (2) Where feasible, flow checks should be made after each installation or change. (3) The direction of fluid flow should be clearly indicated with permanent markings on the exterior of the various components and mating lines. (4) Staggered fittings and different diameter lines are recommended ways to prevent cross-connecting lines.
Electrical Shock, Fire	h. Lines, piping and components within each payload subsystem should be electrically bonded across each connection and should be grounded to reduce static electrical potential.
Fire, Contamination	i. When insulating liquid-carrying pressure lines, the insulating material should be nonabsorbent.
Contamination	j. A positive sealing capability should be provided at the quick disconnect in pressurized fluid and gas lines when these lines are disconnected.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.3 Lines, Tubing, and Hoses (continued)
Contamination	k. Transfer lines, including double-walled lines, should be purged after the transfer of hazardous fluids and before breaking plumbing connections.
Contamination	l. Fluid lines that will be required to be disconnected or severed during payload deployment or separation from the spacecraft should include a check valve or shutoff valve on both sides of the severed point to prevent loss of fluid after disconnection has been made. The system should also be designed so that any line breakage resulting from failure of the disconnecting device to function will occur on the discarded side of the disconnect.
Contamination	m. In the design of liquid and gas systems, consideration should be given to leak testing after installation of the system has been completed.
	3.11.1.4 Connectors and Fittings
Contamination, Fire, Explosion	a. Connectors should be keyed, sized, or located so they cannot be cross-connected thereby minimizing the possibility of connecting incompatible gases, fluids or pressure levels.
Contamination	b. Connectors and fittings which will be disconnected either during ground or flight operations should be provided with tethered end plates, caps, plugs, or covers to protect the system from contamination or damage when not in use.
Contamination	c. Brazed and welded joints are preferred for joining pressure lines since these type joints are less susceptible to leakage problems. Brazed joints were successfully used on the Skylab Program.
Corrosion	d. Criteria for the choice of metallic fittings, sleeves, and connectors should include stress corrosion resistance properties.
Contamination	e. Torque values for all threaded fittings and components should be clearly specified in the design, and special care should be taken to assure that assembly and installation personnel use these values.
Corrosion	f. B-nuts and sleeves made from 2014, 2017, 2024, and 7075 aluminum alloys in the T4 or T6 tempers, or type 303 stainless steel, should not be used because of susceptibility to stress corrosion and leakage.
	3.11.1.5 Filters
Contamination	a. Orifices, close tolerance valves, and contamination sensitive equipment in fluid systems should be adequately protected from contaminants. If the system is designed for periodic flow reversal or the possibility exists that flow reversal could occur, both sides of these items should be protected. The use of properly sized and located filters is recommended for these applications.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.5 Filters (continued)
Contamination	b. Filter design should consider the peculiar demands imposed by orbital operations to remove weightless debris which under normal ground operations would naturally separate and be retained in sumps.
Contamination	c. Filters should be installed in pumps and compressor inlet lines to protect delicate or close tolerance components from contaminants. A differential pressure gage should be installed across such filters when an increase in pressure could become a hazard.
Contamination	d. As a cleanliness measure, all ground support equipment supplying liquids or gases to flight systems should have filters installed as the last components in each supply line.
Contamination	e. Where very close control is required or where a very low contamination level is to be maintained, filters should be placed downstream of each disconnect.
Contamination	f. Filter housings which must be removed from the system to replace filters are not recommended. This procedure merely adds to the possibility of further contamination and filter malfunction.
Contamination	g. Extreme care should be exercised by assembly, test, or flight personnel during any operation requiring opening a line between a device and its protective filter to ensure that additional contamination is not introduced.
	3.11.1.6 Seals and Gaskets
Contamination, Corrosion	a. The materials used for seals, gaskets, fittings, and lubricants should be compatible with the fluids and gases with which they will be used and should meet the cleanliness and contamination requirements of the system. (See section 3.8, MATERIALS, for materials selection guidelines).
Contamination	b. Where extra protection against leakage is desired or where seal damage or wear can be expected, the use of double seals should be considered if each seal can be verified separately and the seal material is compatible with the medium. It may also be desirable to provide seal replacement capability for such applications.
Contamination	c. Any deployable type payload using a fluid system fill and drain umbilical should incorporate a positive seal when the lines are disconnected during the deployment operations. The seal could be provided by a shutoff valve located inboard of the payload disconnect. This would prevent draining or backflow of fluids into the payload bay once the line disconnect has been made.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.7 Valves - General
Explosion, Fire	a. Valves for high pressure oxygen systems (3000 psi range) (211 kg/cm^2) should be slow opening and closing types. Fast operating valves in such high pressure oxygen systems could possibly result in the ignition of contaminants that may be present in the oxygen or trapped at the valve. Also valve components such as seats and seals should not contribute to the contamination of these high pressure systems.
Contamination, Explosion	b. It is not advisable to use soft-seated hand valves, especially upstream of regulators, or other contamination sensitive components in fluid systems. The tendency to overtorque valves by operating personnel could cause the soft seat to rupture, disintegrate, and contaminate downstream component devices.
Contamination, Illness/Injury	c. It is recommended that flow restrictors, orifices, and similar flow limiting devices be installed immediately downstream of any component which could fail open and exceed the flow or relief capacity of downstream elements or compartments. An example on Apollo was the placement of a flow restrictor downstream of the high pressure oxygen regulator valve to protect the crew cabin from overpressurization should the regulator fail open. It is also recommended that flow restrictors or orifices should not be located in a system vent or pressure relief line.
Explosion, Fire	d. Restriction orifices should only be used for pressure regulation under dynamic flow conditions since under static flow conditions the pressure would be equal across the orifice, and the downstream system would no longer be protected from the source pressure.
Explosion	e. Valves should be designed to minimize the generation of shock waves and sudden pressure surges or sudden changes in flow.
Contamination, Fire	f. Valves or similar components that could be operated out of sequence should be provided with interlocks so that flammable or toxic fluids cannot be introduced into a habitable area of the spacecraft.
Contamination, Fire	g. To prevent inadvertent operation of hand operated valves, locking pins or similar devices should be included in the design of these type valves. In addition, manually operated valves should not be used to bypass pressure regulators or other flow control devices.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.8 Pressure Relief Valves
Explosion, Contamination	a. Pressure relief valves should be designed to protect against a pressure regulator's being stuck or failed in the full open position. The particular relief valve should be sized to exceed the maximum flow capabiltiy of its upstream pressure regulator. This capacity is necessary to protect the overall pressure system from further malfunction, system overpressure and possible rupture.
Contamination	b. To protect the low side of a pressure system from the effects of pressure regulation malfunction, the following relief valve settings should be maintained:
	(1) The initial opening of system relief valves should be set in accordance with the hazard potential of the pressurized system.
	(2) Any relief valve initial opening setting should never be higher than the proof pressure level of the protected system.
Explosion	c. In the design of sealed panels, consoles, or similar enclosures which contain liquid or gas system components, consideration should be given to the use of pressure relief devices.
Explosion	d. Where relief valves and burst discs are used in combination, the relief valves should be located upstream of burst discs.
Explosion, Contamination	e. System relief devices should be clearly marked to indicate system function, flow direction, operating pressure setting, latest test data and retest requirement interval.
Explosion, Contamination	f. When pressure vessels are protected by pressure relief devices, flow restrictors should be used when the rate of pressure relief constitutes a potential hazard.
	3.11.1.9 Pressure Regulators
Contamination, Explosion	a. It is recommended that pressure regulators for step regulation be sized to operate in the center 50 percent of their total ranges. Regulators operating at the extreme ends of their operating ranges tend to creep and become inaccurate.
Explosion, Contamination	b. The maximum operating pressure setting of a regulator should not be greater than 75 percent of its maximum pressure regulation capability.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.9 Pressure Regulators (continued)
Contamination	c. If regulator input and output gages are used, they should be located as close as possible to the regulator for accuracy.
Contamination, Explosion	d. Adjustable pressure regulation devices should be plainly marked to indicate the direction of pressure increase and decrease adjustment, the range of pressure control, latest test data, and retest requirement interval.
Contamination, Explosion	e. The operating characteristics of pressure regulator valves should consider the pressure sensitivity of the downstream components to fluctuation or interruption of flow.
	3.11.1.10 Shutoff Valves
Contamination, Fire, Explosion	a. Isolation shutoff valves should be installed in each leg of multiple systems, experiments, or payloads which are supplied from a common liquid or gas pressure source. In this way, any branch of the overall manifolded pressure supply system can be isolated from the others if a failure in that branch occurs. These valves could also be used for independent control over liquids, gases or vacuum being supplied to each experiment or subsystem during test and checkout operations.
Explosion, Contamination	b. Shutoff valves should never be used in series with relief valves unless a burst disc or some other positive relief device is installed to bypass the shutoff valve.
Contamination	c. Shutoff valves should be used at reservoirs and storage vessels if maintenance is required.
	3.11.1.11 Check Valves
Contamination	a. Check valves are not intended to be used as shutoff valves and should not be considered as safety protection against the migration of hazardous vapors or gases.
Contamination	b. Check valves with soft seats should not be tested to higher pressures than the intended design pressure. The seat could later crack and/or disintegrate and could contaminate system elements or destroy the design purpose of the valve.
	3.11.1.12 Pressure Sensing and Monitoring
Explosion	a. A pressure sensing device should be installed on the low side of pressure regulators, at pressure vessels, and at any point in a pressurized system where an upstream overpressure malfunction could exceed the maximum allowable system pressure.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.1.12 Pressure Sensing and Monitoring (continued)
Explosion, Contamination, Injury	b. If a pressure regulation failure or malfunction can be injurious to the crew or the mission, the payload designer should ensure that a pressure readout is readily visible to the crew. An audible warning device should also be provided which will actuate at a predetermined pressure level allowing time for corrective action.
Injury/Illness, Contamination	c. Direct readout pressure gages should be avoided since it is undesirable to route pressurized lines inside inhabited areas. Pressure transducers or other electrical devices should be used for pressure instrumentation.
Injury	d. One consideration in the design of pressure systems is the arrangement of components to allow operation and surveillance from a common point that is relatively safe for personnel. For example, an operator of a high pressure system should not have to leave a remote control station to observe and monitor the system pressures. Valves should be remotely controlled where possible, and maintenance should not be required when the system is pressurized.
	3.11.2 Flight Operations
	None
	3.11.3 Ground Operations
	3.11.3.1 Test and Checkout
Explosion, Collision	a. Prior to installation in a system, pressure vessels, accumulators, fabricated tubing, valves, flexible hoses, and filters should be proof tested to ensure their withstanding internal test pressures higher than design operating pressures without failure or structural deformation. Test fluids should be analyzed for compatibility with the pressure vessel materials used. For example, some fluids can accelerate stress corrosion.
Explosion, Collision, Injury	b. Hydrostatic testing is a relatively safer and more reliable method of system testing than pneumatic proof testing because of the higher stored energy contained in a compressed gas. Even though liquids are generally considered noncompressible and are safer to handle than gases, they do store up energy; therefore, hydrostatic tests must also be considered hazardous.
Explosion, Contamination	c. Pressure system elements that have been modified, damaged, repaired, or disturbed should be retested and/or requalified as applicable.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.3.1 <u>Test and Checkout</u> (continued)
Explosion, Contamination	d. The total number of proof tests to be allowed on each flight operational pressure vessel should be stated as part of the design data. A history of such proof tests should be maintained since an excessive number of proof tests would constitute fatigue cycling which could seriously affect the safety and service life of these pressure vessels.
Explosion, Contamination	e. During "no-yield" proof testing, no permanent deformation of tanks or plumbing alignment should be allowed. Any elastic deformation should be measured during these tests for assurance against abrasive chafing of such pressure vessels and plumbing against adjacent structure during later ground and flight operations.
Explosion	f. Components that have been pressurized at or near their calculated burst or ultimate pressure limits should have no subsequent use other than test. These components should be marked conspicuously and permanently to warn of explosion hazards if pressurized.
Contamination	g. Payload pressurized systems containing hazardous fluids should have an inert gas leak check, under full operating pressure, prior to installation into the orbiter payload bay. Consideration should be given to performing a helium gas low pressure leak test after installation in the payload bay and before propellant loading of the shuttle or other STS elements. This check will assure that leakage rates are acceptable after transport and installation operations.
Explosion, Fire	h. All hazardous payload effluents vented during ground servicing or deservicing should be contained at the shuttle vehicle and later returned to a safe facility disposal area. The presence of free combustibles or oxidizer vapors in the vicinity of the shuttle vehicle and launch pad could create a fire or explosion hazard.
	3.11.3.2 <u>Transfer and Transport</u>
Fire, Contamination, Explosion	a. The handling and transfer of mutually reactive or incompatible fluids should include the following safety practices to protect the operating personnel from potential hazards such as fire, explosion, or release of toxic and corrosive fluids:
	(1) Reactive fluids should not be handled or transferred simultaneously, or the entire system should be completely separated to prevent accidental mixing.
	(2) After fluid transfer, the transfer lines should be purged to neutralize the potentially hazardous effects of trapped or residual fluids.
	(3) Design of fluid systems should prevent the possibility of interconnecting incompatible systems.

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SECTION NO. 3.11 SUBSYSTEM PRESSURE SYSTEMS

ASSOCIATED HAZARD	GUIDELINES
	3.11.3.2 Transfer and Transport (continued)

(4) Procedures should be developed to purge cleaning agents from the fluid system.

(5) Cleaning agents must be compatible with the fluid system with which they are used.

(6) Fluid systems should be identified by function, commodity, pressure limits, and direction of flow.

(7) Parameters such as pressure and temperature should be monitored throughout fluid transfer or transportation periods.

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PROPULSION GUIDELINES

3.12 PROPULSION

System Description.- On certain deployed payloads, propulsion systems are required. The propulsion system functions would include thrust for translation of the payload into orbit that the STS cannot attain, attitude control, scientific platform stabilization or rotation for pointing control, and translation maneuvers to accomplish rendezvous during retrieval operations. The types of propulsion systems (liquid or solid), the propellant combinations (mono-, hypergol, cryogen, etc.), the propellant feed pressure system, the start system (cartridge, tank head, or pressure bottle) are tailored to the particular mission requirements to accomplish scientific objectives. Other influencing factors in the selection of propulsion systems are performance, safety, cost, and compatibility with the STS.

The hardware elements of liquid or solid propulsion systems are designed to contain, pressurize, relieve, deliver, mix, and exhaust the propellants in a controlled manner to produce thrust.

In addition to controls and monitoring electronic equipment, propulsion system elements will generally include:

Liquid Propulsion

- Injector and manifold
- Combustion chamber
- Gimbals and actuators
- Nozzle and extension
- Turbopumps
- Gas generator
- Start cartridge
- Propellant tanks
- Control valves and plumbing

Solid Propulsion

- Motor case
- Nozzle and extension
- Gimbals and actuators
- Propellant grain
- Ignitor/initiator
- Thrust termination devices

Associated Hazards.- The hazards of transporting propulsion systems in the cargo bay of the orbiter are primarily associated with the propellants and pressurants since these are the primary sources of energy for these systems. The main concern is the potential for ignition of free propellants in the orbiter bay and the resultant damage that would be sustained from fire or explosion. Contamination, toxicity, and corrosion are also items of concern for some propellants even if ignition does not occur.

The safety emphasis is to assure that propulsion system propellants do not leak and are not ejected or vented from their containers into the payload bay. It is also important to avoid the presence of ignition sources in the payload bay if propellants do escape. The inert nitrogen gas purge of the cargo bay while the orbiter and payloads are on the launch pad in a serviced condition will limit fire and explosion potentials. The safety of ground personnel is also a concern during the handling, servicing, and installation activities of ground operations associated with payloads with propulsion systems. Flammability and toxicity properties of some propellants are presented in table 3.12–II.

The following safety guidelines can be tailored for specific payload propulsion system applications and indicate possible ways to eliminate or minimize the effects of the hazards. These guidelines generally cover those design and operational elements which are unique to propulsion. Other subsystem guideline sections which are related to propulsion and which should be reviewed for additional safety criteria applicable to propulsion systems include sections 3.13, PYROTECHNICS, and 3.11, PRESSURE SYSTEMS.

TABLE 3.12-II.- FLAMMABILITY AND TOXICITY PROPERTIES OF PROPELLANTS

PROPELLANT	TYPE	FLAMMABILITY	HAZARD	ALLOWABLE CONCENTRATION VALUES 1/ (PPM)	FLAMMABILITY LIMIT (% IN AIR BY VOLUME)	
					LOWER	UPPER
Methyl Alcohol	Fuel	Flammable	Toxic	200.0	@ 68°F (20°C) 6.7	@ 68°F (20°C) 36.0
Ethyl Alcohol	Fuel	Flammable	Narcotic	1000.0	@ 68°F (20°C) 3.3	@ 68°F (20°C) 19.0
Furfural Alcohol	Fuel	Flammable	Irritating, narcotic	50.0	@ 68°F (20°C) 1.8	@ 68°F (20°C) 16.3
Isopropyl Alcohol	Fuel	Flammable	Narcotic	400.0	@ 68°F (20°C) 2.0	@ 68°F (20°C) 11.8
Alkyl Boranes HEF-2, HEF-3	Fuel	Flammable	Highly toxic	0.010	Data classified (see AFM 161-30)	
Anhydrous Ammonia	Fuel	Flammable, explosive when contacted with mercury	Irritating	50.0	@ 68°F (20°C) 16.1	@ 68°F (20°C) 26.8
Aniline	Fuel	Not flammable at room temperature	Toxic	5.0	Vapor explosive when mixed with air	
Chlorine Trifluoride	Oxidant	Reacts vigorously with most known materials, including water	Highly toxic; corrosive, burns skin and eyes	0.10	More reactive than fluorine	
Ethylene Oxide	Monopropellant	Flammable up to 100% vapor concentration	Toxic	50.0	@ 135°F (57°C) 3.6	@ 135°F (57°C) 100.0
Fluorine	Oxidant	React vigorously with most known materials, including water	Highly toxic, corrosive, burns skin and eyes	0.10	Gas and liquid ignite most materials.	
Hydrazine	Fuel Monopropellant	Flammable up to 100% vapor concentration	Toxic, burns tissues	1.0	@ 212°F (100°C) 4.7	@ 212°F (100°C) 100.0
Hydrocarbon Fuels	Fuel	Flammable, sensitive to mechanical shock when mixed with oxidants	Narcotic and can be highly toxic (See Ref 36)	Various (See AFM 161-30)	Ref 2/	Ref 2/
Liquid Hydrogen	Fuel	Flammable	Nontoxic, causes freeze "burns"	Not applicable	4.0	74.2
Hydrogen Peroxide 90%	Oxidant Monopropellant	Nonflammable but supports combustion	Irritating, burns	1.0	Not applicable	
Monomethylhydrazine	Fuel	Flammable between 2.5% and 89% vapor concentration	Toxic	0.50 3/	@ 1 atm 2.5	@ 1 atm 92 to 98
Fuming Nitric Acid	Oxidant	Nonflammable but supports combustion	Toxic, corrosive, causes severe burns	5.0	Not applicable	
Nitrogen Tetroxide	Oxidant	Nonflammable but supports combustion	Toxic, corrosive, burns skin and eyes	2.50	Not applicable	
Liquid Oxygen	Oxidant	Nonflammable but supports combustion vigorously	Nontoxic, causes freeze "burns"	None at std. atmospheres 3/	Not applicable	
Pentaborane	Fuel	Flammable and pyrophoric	Highly toxic	0.0050	Sudden exposure of even small quantities of liquid to air will result in explosion.	
Perchloryl Fluoride	Oxidant	Nonflammable but supports combustion	Irritating, causes freeze "burns"	3.0	Not applicable	
Propyl Nitrate Normal	Monopropellant	Flammable	Toxic	25.0	@ 212°F (100°C) & 1 atm 2.0	@ 212°F (100°C) & 1 atm 100.0
Unsymmetrical Dimethylhydrazine	Fuel	Flammable, hypergolic with some oxidants	Toxic, irritating to skin and eyes	0.50	@ 1 atm & 77°F 2.3 (25°C) @ 302°F (150°C) 1.8 (app)	@ 1 atm & 77°F (25°C) 80 (app) @ 212°F (100°C) 88 to 96 @ 302°F (150°C) 98±2

1/ Parts Per Million (PPM)

2/ See Table 44, Page 131, Bulletin 503, Bureau of Mines, Limits of Flammability of Gases and Vapors

3/ TLV not established, value is approximated.

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SECTION NO. 3.12 SUBSYSTEM PROPULSION

ASSOCIATED HAZARD	GUIDELINES
	3.12.1 Design
	3.12.1.1 <u>SRP (Solid Rocket Propulsion)</u>
Collision, Explosion, Fire	a. Safe and arm devices used on SRP should be equipped with positive safing capabilities during all installation and checkout operations.
Collision, Explosion, Fire	b. After an SRP system is installed in the orbiter payload bay, status of safety critical functions should be displayed to provide warning of unsafe conditions.
Collision, Explosion, Fire	c. Certain weather seals are removed prior to launch while others are left in place at motor ignition. Seals which are not removed should be designed so that they will rupture at motor ignition without leaving remnants that affect flow or pressure.
Explosion, Fire	d. The SRP should be grounded to all other related spacecraft hardware to prevent electrostatic charge buildup or a difference in potential for any reason.
	3.12.1.2 <u>Liquid Rocket Propulsion</u>
Explosion	a. Cleanliness requirements for propulsion propellant lines should be established, monitored, and controlled. Some propellants react explosively with contaminants.
Explosion	b. Closed systems and compartments containing propellants should be capable of in-flight venting through use of the orbiter-provided vent system or should be designed to withstand maximum allowable system pressure.
Explosion, Corrosion, Fire	c. Construction materials for payload propulsion systems should be compatible with the type of propellant used.
Fire, Contamination	d. Nonabsorbent insulation should be used where propellant systems require thermal protection from engine heat or cold environment.
Fire, Contamination	e. Insulation should be inspected for presence of absorbed propellants or other system fluids, and the payload should not be installed in the orbiter if vapors are detected.
	3.12.1.3 <u>Tankage</u>
Explosion, Fire, Corrosion	a. Pressurization of propellants should be accomplished as late as possible (i.e., after deployment where practical) to maintain the payload propulsion system in a relatively passive state while in the orbiter cargo bay.
Explosion, Fire, Contamination	b. Tank filler openings should be located so that when in a one gravity environment, leaking, loose, or unfastened caps will not allow propellants to drain into the cargo compartment.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.12 SUBSYSTEM PROPULSION

ASSOCIATED HAZARD	GUIDELINES
	3.12.1.3 Tankage (continued)
Collision, Explosion, Fire	c. Structural stability of payload propellant tanks should not be dependent upon tank pressurization. Loss of pressure and subsequent structural collapse of a propellant tank in the orbiter payload bay could be catastrophic.
Explosion, Fire	d. Common bulkheads between fuel and oxidizer tanks of hypergolic propellants should be avoided. Also, hypergolic fuels and oxidizers should not be separated by a single weld.
Explosion, Fire	e. Payload propellant tanks should be oriented within the cargo bay for maximum protection from rupture during a crashlanding of the orbiter.
	3.12.1.4 Plumbing (Fill, Drain, Vent)
Collision	a. Dumping, venting, and relief of payload propellants and pressurants should be thrust neutralized to preclude rotational or translational velocities of the payload while in the vicinity of the orbiter.
Explosion, Fire, Contamination	b. Propellant or pressurant lines should not be used to support other components.
Contamination, Fire, Explosion	c. Propellant dump openings should be designed so that there can be no impingement on the payload nor reentry of flammable or corrosive fluids or vapors into the payload.
Explosion, Fire	d. The payload propellant fill, drain, and vent interface with the orbiter should permit main propulsion system propellant loading and replenishing, venting, and emergency detanking with the cargo bay doors closed and latched in a safe mode for launch.
Explosion, Fire, Corrosion	e. Payload propellant lines should be protected from excessive deflection due to the vibrations or accelerations of the space shuttle.
Explosion, Fire, Contamination	f. Absorbent insulative materials should not be used on lines and components containing reactive fluids.
Explosion, Fire	g. Mutually reactive fluids and vapors should not be vented or relieved through the same exhaust ducts.
Explosion, Fire, Contamination	h. Where practical, redundancy should be designed into propellant fluid systems to protect against hazardous fluid leakage.
Fire, Contamination, Injury	i. Fluid systems should be identified by function, fluid, pressure, and direction of flow to reduce the potential for hazardous maintenance or servicing actions.

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SECTION NO. 3.12 SUBSYSTEM PROPULSION

ASSOCIATED HAZARD	GUIDELINES
	3.12.1.5 <u>Control and Monitor</u>
Explosion, Fire, Contamination	a. No single valve operation should result in flow of propellant through a payload propulsion system while it is in the orbiter cargo bay.
Explosion, Fire, Collision	b. A minimum of two discrete and separate command and control events should be provided to initiate opening of propellant flow control valves.
Explosion, Fire, Contamination	c. Capability should be provided to determine payload propulsion system start sequence logic status and valve positions.
Explosion, Fire	d. Payload valve actuation should not be initiated by flight or crashlanding loads.
Explosion, Fire, Contamination	e. If common bulkheads are necessary, simultaneous pressurization of propellant tanks should be performed to avoid hazardous differential pressures.
Explosion, Fire	f. During on-orbit operations, propellant pressurization of the payload propulsion systems should be accomplished after deployment.
Collision	g. Gimbal positions should be monitored and interlocks provided to inhibit firing of a hard-over gimballed engine.
Explosion, Fire, Collision	h. Consideration should be given to instrumenting payload propulsion systems to indicate when established system parameters limits have been exceeded.
Collision	i. Sequential commands for payload attitude hold and main engine ignition should be remotely controlled by the orbiter crew or ground control. Interlocks should be provided to prevent out-of-sequence operation.
Explosion	j. Payload propulsion system electronic equipment that will be powered while in the orbiter payload bay or which operates in closed compartments with propellant lines and components should be explosion proof.
Contamination, Explosion	k. Payloads with thrusting capability should be designed with positive engine isolation capability to insure that "failed-on" or leaking engines can be isolated.

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SECTION NO. 3.12 SUBSYSTEM PROPULSION

ASSOCIATED HAZARD	GUIDELINES
	3.12.1.6 Liquid Propellants
Explosion, Fire	a. Equipment, tanks, transfer lines, and other equipment which can transmit sparks or generate static electricity charges should be properly grounded to prevent the ignition of fuel/ propellant.
Explosion, Fire, Contamination, Corrosion, Injury	b. Propellant transfer systems should be arranged and connected to permit safe and systematic transfer of propellants without loss or contamination. Pumps, valves, and lines should be sized to provide efficient transfer without excessive pressure loss. Construction materials, fabrication methods, and cleaning procedures should be adequate for extended service with the specific propellant. System components should be adequately and rigidly supported with allowance for temperature changes.
Explosion, Fire, Contamination, Corrosion, Injury	c. The hazardous characteristics of each propellant should be documented for the benefit of personnel who may service or work with the payload propellant system. Characteristics to be established include: (1) Threshold limits of toxicity (maximum allowable concentration). (2) Degree of toxicity and irritation. (3) Flammability limits in air. (4) Fire extinguishing agents. (5) Decontamination agents and procedures. (6) Symptoms of exposure. (7) Initial countermeasures and first aid for exposure. (8) Sensitivity to shock and heat. (9) Reaction sensitivity to contamination. (10) Purge gases and procedures.
Explosion, Fire, Contamination, Corrosion, Injury	d. Propellant spills present both contamination and fire hazards. Prevention of spills should be a most important consideration. Some preventive design criteria that should be incorporated into the system are: (1) Only construction materials known to be compatible with the propellant should be employed. (2) The number of mechanical joints should be reduced to a minimum to reduce the probability of propellant or pressurant leakage.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.12 SUBSYSTEM PROPULSION

ASSOCIATED HAZARD	GUIDELINES
	3.12.1.6 Liquid Propellants (continued)
	(3) The system should be designed to withstand safely the maximum operating pressures plus a safety margin.
	(4) The transfer lines should be free from liquid traps.
	(5) An inert gas system should be provided to purge and drain the transfer system without the necessity of dumping residual propellant or disconnecting any system joints.
	(6) The valves, gaskets, and instruments used on the system should be reliable, compatible with the propellant, and should be properly serviced.
	(7) Sufficient control equipment should be provided to isolate portions of the system and to secure transfer equipment for emergencies or component replacement. Remotely controlled equipment should be designed to be fail-safe.
	(8) An inert gaseous blanketing system should be provided to prevent air from contacting propellant.
	(9) The transfer and storage system should be grounded to prevent the buildup of static electricity.
	3.12.2 Flight Operations
Collision, Explosion, Fire	a. The payload propulsion system should not be electrically enabled or mechanically armed while in the orbiter payload bay.
Collision, Explosion	b. A payload propulsion system (excluding attitude control) should be enabled or armed by RF or onboard computer command after a "safe distance" from the orbiter has been achieved. Safe distance should be computed so that no inadvertent or off-nominal operation or failure of the propulsion stage would result in collision with the orbiter or its being struck by the debris of an explosion.
Explosion, Fire, Contamination	c. Where practical, propulsion payloads should be oriented, mounted, and secured in the cargo bay in a manner to minimize orbiter-induced shock and vibration that could initiate propellant flow or engine start.
Contamination, Fire, Explosion	d. Hot gas propulsion and attitude control should not be used for the initial separation of the payload to a safe distance from the orbiter.

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SECTION NO. 3.12 SUBSYSTEM PROPULSION

ASSOCIATED HAZARD	GUIDELINES
	3.12.2 Flight Operations (continued)
Explosion, Fire, Contamination, Collision, Corrosion	e. Propellant system safety critical functions should be rendered safe before recovery of a deployed payload is attempted. This should include remotely commanding all safe and arm devices to "safe," removing power from electrical systems serving safety critical functions or removing power from electrical circuits in the upper stage.
	3.12.3 Ground Operations
	3.12.3.1 <u>General</u>
Explosion, Fire, Contamination	a. Properly trained personnel are required to handle propellants safely. Operating personnel should be thoroughly familiar with the following: (1) The properties of the propellant. (2) Operation of the transfer and storage system. (3) Toxicity and physiological effects of the propellant. (4) Operation and use of the safety equipment. (5) Fire and spill prevention techniques. (6) Fire and spill control measures.
Explosion, Fire, Contamination, Corrosion	b. Detailed procedures with "Caution" and "Warning" notations for loading, handling, and draining propellants should be provided for prelaunch and postlanding activities.
Collision, Explosion, Fire, Injury	c. Solid rocket propulsion initiator and ignitor items should not be installed during ground handling, transport, and storage operations. Installation should be at the latest feasible point during ground preparations for launch.
Explosion, Fire	d. The propellant system should be provided with static electricity protection during ground servicing.
Explosion	e. Buildings which house equipment for handling propellants should be well ventilated to prevent accumulation of vapors.
Collision, Injury	f. Consideration should be given to the use of thrust neutralizers during hazardous ground handling, transporting, and storage of SRP systems.

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SECTION NO. 3.12 SUBSYSTEM PROPULSION

ASSOCIATED HAZARD	GUIDELINES
	3.12.3.2 Test and Checkout
Explosion, Fire, Injury	a. Adequate proof pressure and leak testing of payload propulsion systems and their ground servicing equipment should be conducted before servicing operations at the launch site are performed.
Explosion, Fire, Contamination	b. An inert gas low pressure leak check of payload propulsion fluid systems should be conducted after payload installation into the cargo bay and before propellant loading.
Explosion, Fire, Injury	c. Safe pressures, temperatures, and other parameters which indicate the status of hazardous payload fluids should be verified before handling, transport, or installation and checkout operations begin.
Collision, Injury	d. Periodic proof-load certification of slings, hoists, lifting and handling fixtures, and transporting equipment should be conducted to assure the equipment is in safe operating order.

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PYROTECHNIC GUIDELINES

3.13 PYROTECHNICS

System Description.- Aerospace pyrotechnic devices consist of gas generators, detonators, start cartridges, explosive or frangible bolts and nuts, rocket motors, destruct systems, control elements, emergency flow control valves, etc. Functional applications for pyrotechnic devices continue to evolve. Payloads will have many applications for pyrotechnics. Some of the more obvious are tank pressurization valves, emergency dump valves, separation systems, and gas-operated deployment, retrieval and tiedown mechanisms.

Pyrotechnic systems contain many elements that control and monitor the functional devices. Control elements include switches, initiators, ignitors, logic circuits, firing circuits, and power supplies (usually separate dedicated batteries) with arm/disarm capability, and safe and arm mechanisms. Monitor elements include circuit continuity test capability, safe and arm mechanism position indicators, safety pin streamers, and payload system measured parameters that indicate the functional status of the device.

Pyrotechnics are initiated by activation of a fire switch after all prerequisite event interlock contacts have been closed and the necessary mechanical and electrical arming events have been accomplished. At fire switch activation, a low level electrical pulse progresses from the electrical power source through the firing circuit to the initiator bridgewire. The bridgewire heats and initiates the explosive train. There are many types of explosive trains. A common type uses explosives of progressively higher thermal energy output to reach the ignition temperature of the final pyrotechnic charge. This final charge is designed to accomplish the pyrotechnic function, whether it is ignition of a solid rocket motor, extension of a solar array by a gas-driven actuator, or separation of a bolt by explosion.

Payload pyrotechnic functions will normally be controlled through an electrical interface with the STS or directly from ground control. Firing commands and measurements may be telemetered from and to the STS or ground control, and they may be hardwired from and to the orbiter payload control console and caution and warning system if provided. The sensitivity of payload pyrotechnic devices to stray electrical energy, temperature, vibration, and shock of the STS environment should also be a design consideration.

Pyrotechnic devices may control structural, electrical, or fluid interfaces between payloads and the STS. Tiedowns may be severed by explosive bolts in an emergency mode (i.e., backup to electromechanical separation). Electrical interfaces may be guillotined. Fluid interfaces may be opened for emergency dumping or may be shutoff and severed for payload jettisoning.

To take advantage of previous experience, JSC 08060A, "Space Shuttle System Pyrotechnic Specification," has been established and applies to all pyrotechnics in the space shuttle, to all NASA Centers with shuttle responsibilities, and their contractors or suppliers. JSC 08060A contains a "Shuttle Preferred Pyrotechnic Items List" which describes specific devices that have proven successful in previous programs. These devices meet the current shuttle requirements.

The NSI (NASA standard initiator) which is a new designator for the earlier SBASI (single bridgewire Apollo standard initiator) used on the Apollo and Skylab Programs and Apollo Soyuz Test Project will be supplied as GFE (Government-furnished equipment) by NASA JSC to all STS users. NASA has concluded that the NSI can satisfy 90 to 95 percent of the STS requirements. In addition, the PIC (pyrotechnic initiator controller) used to safe, arm, and fire the NSI has been standardized throughout the shuttle vehicle and should be used for payload applications where practicable.

There are two GSE (ground support equipment) items that are common and will be supplied as GFE by NASA JSC. These items are (1) the NSI firing unit which simulates the firing of the PIC and (2) the initiator resistance measuring equipment which is a special digital ohmmeter used for NSI acceptance and preinstallation tests.

Associated Hazards.- The general hazards associated with the accidental release of the explosive, propulsive, or thermal energy of pyrotechnic devices are well recognized. Individual safety analyses are required to determine the hazards of premature pyrotechnic events during progressive phases of the mission or the effects of failure to function when required. Premature performance or nonperformance of pyrotechnic functions can be critical to personnel survival and the preservation of the system.

Premature extension of a payload antenna or solar array in the cargo bay of the orbiter could injure personnel during ground operations. While on orbit, premature extension could inflict sufficient damage to the orbiter cargo door or the thermal protection system to render the orbiter unsafe for entry.

Failure of a propellant dump system to function in an emergency could increase the hazard of an abort or crashlanding because of the retention of significant amounts of propellants onboard during the emergency.

Most hazards of premature or accidental activation are created by procedural or human error, stray electromagnetic energy from peripheral equipment, or the environment. Sequential event interlocks, electrical arm/disarm firing circuit interrupts, and mechanical safe and arm devices can be used to preclude a single failure from inadvertently initiating pyrotechnic events.

The evolution of pyrotechnic device design, manufacturing, and testing practices has resulted in exceptional reliability of pyrotechnic systems to function when commanded. When the redundancies usually incorporated in aerospace pyrotechnic systems are included, the probability of their performing when required has been historically high. When a nonignition failure does occur, it can usually be traced to failure to receive an electrical command. Lesser contributors to nonperformance of qualified pyrotechnic items are out-of-control processing or excessive environmental exposure.

The following section presents pyrotechnic safety design and operational guidelines that have been developed during years of aerospace experience. It is also suggested that the JSC listing of NASA-preferred pyrotechnic devices that are qualified for certain applications be reviewed by payload designers. This review could identify off-the-shelf devices for some payload applications that are already designed and qualified.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.13 SUBSYSTEM PYROTECHNICS

ASSOCIATED HAZARD	GUIDELINES
	3.13.1 Design
	3.13.1.1 General
Loss of Entry Capability	a. Safety critical pyrotechnic functions should have redundant sequence logic and firing circuits through dual initiators so that no single electrical, mechanical, or chemical failure would prevent circuit operation.
Explosion, Collision	b. Pyrotechnic device installations should be designed for ease of access, arming, safing, and removal.
Explosion, Temperature Extremes, Injury	c. Pyrotechnic devices should be located within the system away from thermal zones that may approach the devices' safe-temperature limits. Where avoidance of excessive temperature zones is impossible, thermal insulation and heat sinks should be used to control the temperature within safe limits for the pyrotechnic device.
Explosion	d. Pyrotechnic devices should be designed so that the metal exterior can be electrically bonded to vehicle structure.
Loss of Entry Capability	e. Pyrotechnic units that are not intended for flight use should be color coded for conspicuous identification.
Explosion, Collision	f. The access, electrical circuitry, and test points of pyrotechnic units should be clearly marked in a distinctive manner.
Explosion, Collision	g. Pyrotechnic device explosive or propellant filled volumes should be designed to allow verification of content by neutron ray inspection or by other nondestructive test methods.
Explosion, Contamination	h. Pyrotechnic devices should be hermetically sealed to protect the propellants and explosives from moisture or evaporation.
Explosion	i. All pyrotechnic system threaded connections should be designed for positive locking for flight operations.
Explosion, Collision	j. Pyrotechnic device housings should be designed to prevent debris damage to interfacing equipment from fragments created by an explosion.
Fire, Contamination	k. Pyrotechnic exhaust products should be contained or controlled to prevent ignition or contamination of interfacing equipment.
Fire	l. Magnesium should not be used in the fabrication of pyrotechnic devices as it creates an additional fire hazard.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.13 SUBSYSTEM PYROTECHNICS

ASSOCIATED HAZARD	GUIDELINES
	3.13.1.2 <u>Destruct</u>
Explosion	Should a waiver be granted to allow a payload to have self-destruct capability, the command/destruct circuitry and mechanical interruption of the explosive train should be sufficiently inhibited to ensure a capability to make the system inert on command from the orbiter or from ground control.
	3.13.1.3 <u>Safe and Arm</u>
Explosion	a. If a waiver has been granted for a destruct system, its safe and arm device should have a positive mechanical lock (i.e., safety pin) that prevents movement from the safe to the armed position. Removal of the safety pin should not cause the unit to arm. The safe and arm devices shall have positive indexing, and visual indication of the safe or armed position.
Explosion, Injury, Collision	b. Remote monitoring and local visual inspection capability should be available for determining the status of mechanical safe and arm devices.
	3.13.1.4 <u>Electrical Circuitry</u>
Explosion, Collision	a. Deployable payload pyrotechnics should have the capability of being armed after safe distances from the STS are verified.
Explosion, Collision	b. Circuit breakers and activation switches used to arm and initiate pyrotechnic devices should be located, guarded, placarded, and procedurally protected to avoid inadvertent activation.
Explosion, Collision	c. The safe and arm device control and monitor circuits should be completely independent of the firing circuits with separate noninterchange-able electrical connectors. Arming and monitoring should not initiate pyrotechnics.
Explosion, Collision	d. There should be an arm and disarm interrupt of the firing circuit of pyrotechnic devices with remote control to either position to allow arming of pyrotechnics as late as possible in the mission sequence.
Explosion, Collision	e. The arm and disarm status of firing circuits and discrete indications of pyrotechnic events should have remote monitoring capability to provide warning of hazardous conditions.
Loss of Entry Capability	f. Firing sequence logic should receive power from a source other than the pyrotechnics batteries to avoid possibility of inadvertent arming and firing of pyrotechnic devices.
Collision, Loss of Entry Capability	g. Pyrotechnic firing circuits should be separated from other powered circuits to the maximum extent practical to avoid shorts between circuits that could fire the pyrotechnic device.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.13 SUBSYSTEM PYROTECHNICS

ASSOCIATED HAZARD	GUIDELINES
	3.13.1.4 Electrical Circuitry (continued)
Collision, Loss of Entry Capability	h. Where separation of firing circuits from powered circuits through connectors is impractical, pin-to-pin and pin-to-case separation and electrical resistance should be maximized.
Collision, Loss of Entry Capability	i. Circuit and pin assignments within a connector should be such that any single short circuit occurring as a result of a bent pin will not allow current to be applied to the pyrotechnic subsystem circuit.
Explosion, Collision	j. The firing circuit disarm interrupt should be as close to the pyrotechnic device as possible to prevent antenna effects from energizing the circuit.
Explosion, Collision	k. Firing circuits should be of minimum length and should use twisted wire pairs to minimize receipt of stray electrical energy from other circuits, RF sources, or buildup of a static charge.
Explosion, Collision	l. Firing circuit shielding should be continuous from the power source to the case with no gaps. Shielding should be grounded to the payload structure at both ends where possible.
Loss of Entry Capability	m. The firing circuitry should be designed to protect the power supply from a power drain in the event the device short circuits upon activation.
Explosion, Collision	n. Pyrotechnic circuits should be isolated to prevent adverse effects from transients and ground loops. The firing circuit should have a separate return line to the power source for each initiator.
	3.13.1.5 Initiator Characteristics
Explosion, Collision, Injury	a. The NSI or its equivalent should demonstrate a "no-fire" threshold when one ampere of direct current or one watt of power is applied for 5 minutes.
Loss of Entry Capability	b. The "all-fire" reliability of the NSI or its equivalent should be demonstrated by test and analysis.
Explosion	c. Initiator pin-to-pin and pin-to-case resistance should be established to preclude shorts or static charge/discharge through the bridgewire. Compliance should be demonstrated by test and analysis.
	3.13.1.6 Propellants
Explosion	a. Propellant-operated devices such as mortars, thrusters, and circuit interrupters should demonstrate a structural capability of firing in a locked-shut mode without fragmentation.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.13 SUBSYSTEM PYROTECHNICS

ASSOCIATED HAZARD	GUIDELINES
	3.13.1.6 Propellants (continued)
Contamination	b. Solid propellant rocket motor or liquid rocket engine start cartridge nozzle weather seals that rupture or expel at motor ignition should not leave remnants that significantly alter the flow through the nozzle, affect the pressure in the chamber, or damage the turbine blades or nozzles.
	3.13.1.7 Explosives
Explosion	a. The number and types of high explosives should be minimized. HNS, HMX, and RDX are the preferred high-explosive materials (in that order) because of their thermal-vacuum characteristics and their relative insensitivity to shock.
Loss of Entry Capability	b. No splicing of LSC (linear shaped charges) or MDF (mild detonating fuse) should be allowed. This will eliminate one possibility for interrupting the explosive train.
	3.13.2 Flight Operations
Explosion, Collision, Injury	a. To reduce their susceptibility to inadvertent firing, pyrotechnics should be armed as near to the time of expected use as is practical without compromising reliability .
Explosion, Collision, Injury	b. To limit exposure to inadvertent firing, pyrotechnics should be disarmed promptly when they are no longer needed.
	3.13.3 Ground Operations
	3.13.3.1 General
Explosion, Injury	a. Special clothing that is flame retardant, static free, and with grounding provisions should be used during pyrotechnic installation.
Explosion, Injury	b. Materials capable of generating static-charges should not be used for pyrotechnic item packing, shipping, or ground handling.
Explosion, Injury	c. The suppliers of pyrotechnic devices are responsible for obtaining the proper explosives classification and the regulations for packaging, shipping, and storage of explosives. The Space Shuttle System Pyrotechnic Specification, JSC 08060, provides the basis for control of all space shuttle pyrotechnics at the various levels of activity and should be considered for use by the payload developer.
Explosion, Injury	d. Pyrotechnic handling, installation, checkout, and test operations should be conducted by technically qualified personnel in accordance with approved detailed procedures.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.13 SUBSYSTEM PYROTECHNICS

ASSOCIATED HAZARD	GUIDELINES
	3.13.3.1 General (continued)
Explosion, Injury	e. When conducting operations involving pyrotechnics, the minimum number of personnel should be exposed to the smallest quantity of pyrotechnics for the shortest time consistent with safe operations.
Explosion, Injury	f. Procedures should be written for ground operations involving pyrotechnics. These should include specific safety precautions such as grounding requirements, number of personnel, required tools, and electrical checkout equipment.
Explosion, Injury	g. Safe and arm device safety pins should be marked with a streamer when installed. Removal of the safety pin should be as late as practical before launch.
	3.13.3.2 Installation
Explosion, Injury	a. RF silence should be established and maintained during installation and electrical connection of pyrotechnics.
Explosion, Injury	b. Sensitive initiating elements should be installed in the system just prior to electrical hookup as late as possible before launch.
Explosion, Injury	c. Shielding caps should be installed on initiators during shipment, handling, and storage. The cap's outer shell should be conductive, provide an RF shield, and make a positive electrical contact with the case. The cap should not be closer to the pins than the pins are to the case.
	3.13.3.3 Test
Explosion, Injury	a. Continuity test equipment should not be capable of delivering sufficient current to initiate or degrade pyrotechnic devices. (Standard ohmmeters may be capable of providing sufficient current to initiate pyrotechnics.)
Explosion, Injury	b. A hazardous-current test of pyrotechnic circuits should be conducted prior to making firing-circuit connections, and any residual current in the circuit should be eliminated before making the connection.

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RADIATION GUIDELINES

3.14 RADIATION

System Description.- On all previous manned space programs, the harmful effects of natural and artificial sources of radiation were minimized by careful attention to cabin and equipment shielding design, limits to radiation sources allowed onboard, allowable crew exposure times, and accurate monitoring of radiation levels. It is of primary interest that such safe radiological controls be continued on the STS program and proposed payload elements.

NASA implementation of NRC (Nuclear Regulatory Commission) rules and regulations requires that the use of radioactive sources in the payloads to be flown on the STS must be reviewed and approved by JSC. This approval process may be initiated by use of JSC form JSC-44 which may be obtained from the JSC Space Shuttle Program Office. For payloads using RTG's (radioisotope thermoelectric generators) such as SNAP (systems for nuclear auxiliary power) and similar devices, approval will involve procedures identified in the NASA ERDA (Energy Resources and Development Agency) Interagency Agreement 1052.72A.

There are various sources of ionizing radiation and electromagnetic interference type radiation which must be adequately controlled on payload elements to prevent damage to the shuttle spacecraft, other payload components or experiments, and the crew. Radiation-sensitive equipment includes ordnance system pyrotechnic circuits, communications, and orbiter control systems. Examples of potential payload radiation sources or devices include:

1. RITE (radioisotope for thermal energy) fuel capsule.

2. Isotope Brayton power conversion system using heat capsules containing radioactive material such as plutonium 238.

3. Nuclear reactor power source.

4. Radionuclide tracers, calibration, and check sources.

5. X-ray emitters, particle accelerators, vidicons.

6. Radar or communication antennas.

7. Microwave generators.

Lasers are another source of radiation; because they are optical devices, safety guidelines concerning these payload elements are enumerated in section 3.10, OPTICAL.

Associated Hazards.- Payload radiation sources may significantly contribute to the radiation levels to which the crew of the orbiter may be exposed, and these should be shielded and controlled. Table 3.14-III shows the current radiation exposure limits established for flight crewmen. The limits presented in the table have been established by the Radiation Safety Panel for Manned Spaceflight and represent the total allowable radiation limits for the crew from all sources. As a general guide, individual payloads should be designed to a factor of one hundred below the limits presented in table 3.14-III, and any requested deviations should be reviewed and evaluated on an individual basis.

TABLE 3.14-III.- RADIATION EXPOSURE LIMITS AND EXPOSURE RATE CONSTRAINTS FOR UNIT REFERENCE RISK*

Constraints	REM**		
	Bone Marrow (5 cm)	Skin (0.01 mm)	Eye (3 cm)
1-year average daily rate	0.2	0.6	0.3
30-day maximum	25	75	37
Quarterly maximum	35	105	52
Yearly maximum	75	225	112
Career	400	1200	600

*For details, see "Radiation Protection Guides and Constraints for Space Missions and Vehicle Design Studies Involving Nuclear Systems, Report of the Radiobiological Advisory Panel of the Committee on Space Medicine, Space Science Board, National Academy of Science, 1970."

**REM (Roentgen equivalent man) REM is a unit of radiation dose equivalent. For details, see "International Commission on Radiation Protection," Publication No. 9, 1966.

In addition to crew injury, the principle equipment oriented radiation damage considerations are bulk (crystal) damage and ionizing (surface) effects associated with semiconductor electronics, ionization effects in materials, and dynamic interference effects in sensors. The most sensitive components to bulk damage are light emitting diodes in solid state displays and high power semiconductors. Other radiation sensitive devices include grazing incidence X-ray telescopes, air-glow photometers, and nuclear gamma ray spectrometers for high energy stellar astronomy.

Electromagnetic radiation, generated by the operation of radar equipment, induction heaters, or communications equipment, can be hazardous if it is of sufficient magnitude to affect the firing circuits of ordnance devices. It could also affect electronic control circuits, disrupt the transmission of data and other communication to and from ground stations, and be hazardous to personnel.

The guidelines in this section deal with the handling, shielding, servicing and other means of limiting radiation sources such as radioisotopes and nuclear reactor power sources and radioactive materials such as paint and similar coatings. Electromagnetic and microwave sources of radiation are also covered.

A report illustrative of guidelines and background for the design, control, and operation of ionizing radiological equipment is provided by the General Electric study 72SD4201 completed in January 1972, titled "Manned Space Flight Nuclear System Safety."

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.14 SUBSYSTEM RADIATION

ASSOCIATED HAZARD	GUIDELINES
	3.14.1 Design
	There are various and specific Government regulations regarding the use of major radioactive sources. The guidelines in subsection 3.14.1.1 deal with typically large radioactive sources and suggest design practices for safe utilization. The guidelines in subsection 3.14.1.2 cover typically small radioactive sources. The JSC Space Shuttle Program Office should be contacted for instructions and applicable requirements for safe usage and handling of all these materials.
	3.14.1.1 <u>Ionizing Radiation Sources</u>
Contamination, Radiation	a. Isotope and reactor systems using liquid metal in heat transfer loops should be designed for safe handling and freedom from liquid metal loop leakage. Liquid metal reacts violently with water and moist air. To minimize the effects of this hazard, the following options should be considered:
	(1) Toxic, corrosive, or explosive coolants should be avoided where feasible. Power conversion systems featuring the Brayton cycle or the organic Rankine cycles permit relatively low temperature operation allowing the use of nonliquid metal coolants.
	(2) Double-walled containment of the liquid metal should be provided throughout the coolant loop.
	(3) An inert, dry gas blanket around the heat source should be used during all storage, transporting, and launch operations following assembly of isotope heat source components.
	(4) Liquid metal leak detection should be provided during all operational phases.
Explosion, Contamination, Radiation	b. Adequate blast overpressure, fragmentation, and fireball protection should be provided to assure containment of all radioactive material if an accident occurs.
Radiation	c. Payloads containing reactor or isotope systems, tracers, X-rays, cathode ray tubes, radar, and other sources of ionizing radiation should be shielded, oriented, or otherwise limited to prevent exceeding crew radiation limits outlined in table 3.14-III and as controlled by the Radiation Safety Panel at JSC.
Radiation	d. Reactor and isotope systems should be instrumented to allow ground and flight crews to monitor radiation levels of critical elements and temperature and pressure of the primary heat transfer loop to detect leakage and thermal performance.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.14 SUBSYSTEM RADIATION

ASSOCIATED HAZARD	GUIDELINES
	3.14.1.1 <u>Ionizing Radiation Sources</u> (continued)
Radiation	e. A redundant lockout circuit should be provided to prevent inadvertent activation of a nuclear system.
Explosion	f. A redundant automatic means of reactor shutdown should be provided to control operation under all contingencies.
Radiation, Injury	g. Direct visual or TV coverage should be provided during isotope/component transfer to allow the ground or flight crews to see that the radioactive material is properly located and shielded.
Radiation, Injury	h. Equipment should be provided for locating radioactive material which has been inadvertently released in a manned area or module.
Temperature Extremes, Injury	i. The design of payload reactor coolant loops that use liquid metal as a primary coolant should not require breaking or opening during orbital operations because of the very high temperatures involved.
Radiation	j. Tracking and recovery-locating devices should be provided on nuclear payloads to facilitate land or water recovery if the payload is jettisoned.
Radiation, Explosion, Injury	k. A reactor jettison system capability should be provided with all nuclear payloads to protect the crew and vehicle. Safe procedures should also be established for the disposal of radioactive waste or radiation-contaminated material.
Radiation, Explosion	l. A positive and permanent shutdown system should be provided for malfunctioning reactors and for reactors which have completed their missions.
Radiation, Injury	m. Design of nuclear hardware should include intact reentry and impact to protect the general public from potentially dangerous radiation.
	3.14.1.2 <u>Radioactive Materials</u>
Radiation, Contamination, Injury	a. The use of radioactive materials in spaceflight presents unique handling and contamination problems. It is recommended that any proposed use be carefully considered and that alternative approaches be evaluated where practical and economical.
Radiation, Contamination	b. Radioluminescent materials should have positive mechanical protection against abrasion, flaking, or direct crew contact. Radioactive paints used for illuminating panel instrument nomenclatures should be avoided. The deposited energy from radioactive material will eventually break the paint bond releasing particles into the atmosphere where they could be ingested by the crew or lodge in their eyes.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.14 SUBSYSTEM RADIATION

ASSOCIATED HAZARD	GUIDELINES
	3.14.1.2 Radioactive Materials (continued)
Radiation, Contamination, Injury	c. Where radioluminescent material best satisfies system requirements, the following precautions should be taken: (1) Each proposed use of radioluminescent material should be approved through the JSC Space Shuttle Program Office. (2) Only the minimum amount of the radioactive materials should be used. (3) Radioactive materials should be completely sealed or encapsulated in substances having low damage potential from the inherent radiation. (4) The seals for radioactive material should withstand damage due to ground or space environment, accidents, or mishandling. (5) The component bearing the radioactive substance should be designed for replacement with no damage to the seal of the radioactive substance. (6) The substance to which radioactive paint or similar coating is applied should be rigid enough to prevent paint flaking due to flexure. (7) Each item containing radioactive material of a quantity sufficient to require NRC licensing should be permanently marked in a manner approved by the JSC Space Shuttle Program Office.
Illness/Injury	d. In general, components containing radioactive materials should be labeled "Radioactive Material" in accordance with NRC rules and regulations. Systems hardware containing these components should be brought to the attention of the JSC Space Shuttle Program Office.
Radiation, Contamination	e. To minimize the probability of radioactive material spillage and the effects thereof, the following precautions should be considered: (1) Properly shielded and firmly secured storage vaults should be provided for radiation sources. (2) Special caution and warning sensors in conjunction with STS provided instrumentation may be advisable to detect any level of radiation leakage from storage vaults or containers. (3) Special clothing should be provided for personnel involved in handling or using radioactive materials. The need for protective clothing will depend on the nature of the operation and the degree of containment of the radioactive material.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.14 SUBSYSTEM RADIATION

ASSOCIATED HAZARD	GUIDELINES
	3.14.1.2 Radioactive Materials (continued)
	(4) Strict procedures should be provided for the handling and use of radioactive materials.
	(5) Spare shielded containers should be available in which radioactive material can be temporarily stored in the event of an accident.
	(6) All components and equipment containing radioactive materials should have redundant seals to protect against leakage.
	3.14.1.3 Electromagnetic Interference/Microwave
Explosion, Loss of Entry Capability	a. Adequate shielding of control and communication equipment, pyrotechnic devices, and other critical equipment is needed to prevent loss of control or monitoring functions because of saturation of electronic circuits and to prevent initiation of explosive devices from induced currents.
Illness/Injury	b. It may be necessary to provide a backup (emergency) communications link that will not be affected by EMI or to establish procedures and schedules which consider the periodic disruption of normal communications.
Explosion, Injury, Shock	c. Induction heaters are a potential source of EMI. The EMI signature of all such heaters considered for use should, therefore, be determined, and the unit exhibiting the lowest EMI should be the preferred unit.
Injury	d. When EVA activities are required, a means should be provided to isolate all power from equipment generating microwave and/or electromagnetic radiation.
Injury	e. To protect personnel during ground operations, shields, guards, and warnings should be provided where EMI emitting equipment is operating. Strict procedures should also be provided for these operations.
Radiation	f. Radio frequency equipment should be shielded to prevent continuous exposure of personnel to RF levels greater than 10 MW/CM^2. This level has been adopted by many Government agencies as a standard to prevent acute and chronic RF radiation damage to any organ of the body.
	3.14.2 Flight Operations
Contamination, Injury	a. To prevent possible radiation leakage danger to ground and flight crews, nuclear reactor power modules should be designed for transportation to space while in a preoperational mode. The reactor should not be activated while in immediate proximity to the orbiter.
Radiation, Injury	b. To protect the flight crew, on-orbit nuclear cargo transfer operations should not require EVA.

ASSOCIATED HAZARD	GUIDELINES
	3.14.2 Flight Operations (continued)
Radiation, Injury	c. Unauthorized personnel should be restricted from using radiation producing equipment or handling and using on-board radioisotopes. The installation of appropriate caution signs and other means of warning featuring visible or audible signals should be considered.
	3.14.3 Ground Operations
Radiation, Explosion, Contamination, Injury	a. Once assembled, an isotope heat source is active and continuously emits radiation and heat. A redundant ground cooling system should be provided to dissipate this heat during prelaunch operations. Radiation shielding for the protection of ground crews and critical equipment should also be provided at this time. The following guidelines should be considered to minimize these concerns:
	(1) Radioactive material should be assembled in radioisotope power systems as late in the countdown sequence as feasible to reduce the hazards to the crew and equipment and to provide minimum impact on prelaunch operations.
	(2) The isotope heat source ground cooling system should be designed so that two failures must occur before system cooling is lost.
	(3) The isotope ground cooling system should be adequately instrumented to sense any loss or degradation of heat dissipation capability.
Radiation, Injury	b. Payloads producing nuclear radiation of sufficient quantity to create hazards to the general public should be transported in protective modules or casings capable of withstanding a launch vehicle explosion on the pad and worst-case reentry and crashlanding contingencies.
Radiation, Injury	c. Any ground support equipment used within the spacecraft and which requires the use of radioactive materials should be designed to control the level of external emissions to protect personnel and STS subsystems from detrimental effects.

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STRUCTURES GUIDELINES

3.15 STRUCTURES

System Description.- The structural subsystem consists of beams, plates, housings, brackets, braces, attachment fittings, structural fasteners, and other types of metal or nonmetal members whose functions are to support components or to attach integrated payloads. The payload members are passive, i.e., they do not utilize, control, or develop energy. They resist corrosion from the use environment and absorb energy in the form of load stresses and heat. These internal stresses weaken the molecular structure of the materials and can initiate crack formation and subsequent structural failures. Structural failures can be catastrophic and cannot be tolerated in spaceflight operations. It is, therefore, essential that considerable effort be spent in the analyses and selections of materials for characteristics which are compatible with the use environment.

Associated Hazards. The associated hazards with payload structures are collision, corrosion, injury, and loss of orbiter entry capability. They are created when a structural member fails under stress. The failures can be of two types; plastic deformation, or a brittle failure. The latter is more critical in the design of safe payload structures.

In metallic materials, the brittle failures are caused by stress corrosion, hydrogen embrittlement, and structural fatigue. In aerospace usage structural failures due to stress corrosion cracking have been numerous enough to warrant attention. Criteria and recommended practices have been developed and are documented in NASA SP series technical reports. Materials and alloys susceptible to corrosive effects are also identified in the reports, and their use should be avoided. The reports also discuss analytical techniques such as fracture mechanics to provide methodology for understanding and controlling crack formations in structural elements. Applicable criteria and practices from these reports are summarized in the guidelines of this section.

The acceleration/deceleration forces created by launch, orbit, and entry environments as well as as abort or crashlanding conditions are stated in the Space Shuttle Payload Accommodation Document, JSC 07700, Volume XIV, and should be considered in structural designs. Emphasis is placed on preventing structural failures which can cause equipment to become projectiles that can enter the crew compartment and injure the crew. Failures of primary structural elements of automatic payloads during deployment can pose collision hazards with the orbiter as well as injury potentials to the crew.

Certain material used in structural applications in the space environment have been found to outgas and emit toxic fumes creating hazards to personnel. In this sense, the structural subsystem guidelines will overlap with the guidelines developed in Section 3.8, MATERIALS. The structural subsystem also overlaps with the mechanical subsystem (see section 3.9, MECHANICAL). These subsystems should be reviewed by the structural designer.

The safety guidelines in this section are written to recommend adequate structural analysis in the design of payload structures and selections of materials compatible with the use environment. Suggestions are also included with regard to crashlanding provisions for containing payload equipment to preclude crew injury. MSFC drawing 10M33107A, "Design Criteria for Controlling Stress Corrosion," should be reviewed for additional information on stress-corrosion cracking.

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SECTION NO. 3.15 SUBSYSTEM STRUCTURES

ASSOCIATED HAZARD	GUIDELINES
	3.15.1 Design
	3.15.1.1 <u>Structural Analyses</u>
Collision, Corrosion, Injury, Loss of Entry Capability	a. Structural analyses should be performed on all payload structures to show that all elements of the design, such as the strength, stiffness, structural stability, and fatigue, meet all specified criteria for the anticipated loads and environments, including crashlanding loads. The analyses should include static and dynamic stress analysis and vibration analysis for loads and environmental data. The analyses should be compiled and documented. Structural analyses should be performed on payloads which were originally designed for launch environments other than the STS. Overall loads analysis for the combined payload/shuttle structure should be performed.
Collision, Injury, Loss of Entry Capability	b. To reduce potential hazardous effects of stress concentrations in primary structure, some general practices which should be considered in the structural analyses and design are to:
	(1) Use multiple load path structure where permissible.
	(2) Make gradual changes in sections and symmetry of design.
	(3) Minimize the number of cutouts and discontinuities in primary elements.
	(4) Design for the peak stress rather than the average stress to be carried by structural members, especially at stress concentrations.
	(5) Avoid attachment of secondary brackets, fittings, handles, steps, and hoses to areas of high stress.
	(6) Avoid use of rivets to carry repeated tensile loads.
	(7) Eliminate sharp edges for personnel safety and to reduce stress concentrations.
	(8) Select fasteners of sufficient size and proper material to carry design loads and impose proper pressure on joints through pretension.
	(9) Provide allowances for distortions and stresses resulting from thermal expansion and contraction of the space temperatures.
Corrosion	c. Fracture mechanics technology should be applied as design criteria in analysis of flaw growth and fracture characteristics of materials. Specific applications include pressure vessels and glass enclosures.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.15 SUBSYSTEM STRUCTURES

ASSOCIATED HAZARD	GUIDELINES
	3.15.1.2 Structural Materials
Corrosion	a. If aluminum alloys are considered for structural applications, either coated or chemically treated alloys which are less susceptible to general corrosion and pitting or alloys with tempers having high resistance to stress-corrosion cracking should be used. Certain alloys are more susceptible to stress-corrosion cracking under high sustained tensile stresses when exposed to salt air ambient typical of sea coast atmosphere.
Corrosion	b. Caution should be exercised in the selection of high strength, low alloy steels heat-treated to high strength levels (180,000 psi) (12,656 kg/cm^2) and above as they are extremely sensitive to stress corrosion. Because of the relationship between strength and susceptibility to stress-corrosion cracking, it is a recommended practice to use the lowest strength material compatible with design.
Corrosion, Loss of Entry Capability	c. Strict material control should be maintained on high strength, low alloy, heat-treated steels to avoid inducing residual stresses by machine operations of any kind after heat treatment. Steel parts which have been acid cleaned, plated, or exposed to hydrogen through use of acid pickling process, and hydrocarbon lubricants, should be baked and checked for hydrogen embrittlement. Cadmium plated tools should not be used on assemblies of high strength steel parts that are to be operated under load at temperatures above 450°F (230°C). Small deposits of cadmium may be left on the part which can lead to metal embrittlement and subsequent structural failure.
Corrosion	d. In the use of titanium, procedures should be provided to assure careful use of cleaning fluids or other chemicals which can induce stress-corrosion cracking, hydrogen embrittlement or can reduce fracture toughness. The use of hydrochloric acid, cadmium compounds, chlorinated cutting oils and solvents, methyl alcohol, and compounds containing mercury with titanium should be avoided.
Corrosion	e. Structural materials should have high tolerance for flaws throughout the anticipated service life of the structure. These materials should be resistant to brittle crack propagation in the use environment.
Corrosion	f. In the design of payload structure which can create hazards to personnel, materials should be selected to be free from stress-corrosion cracking throughout their service life. This may be accomplished by an effective combination of the following:
	(1) Identification and control of the environments to which the structure will be exposed during construction, storage, transportation, and use.
	(2) Selection of alloy compositions and tempers having high resistance to stress-corrosion cracking in the use environment.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.15 SUBSYSTEM STRUCTURES

ASSOCIATED HAZARD	GUIDELINES
	3.15.1.2 Structural Materials (continued)
	(3) Control of fabrication and other processes which may introduce residual tensile stresses or otherwise damage the material.
	(4) Limitation of the combined residual and applied tensile stresses to below the threshold stress level for the onset of cracking through the service life of the vehicle.
	(5) Establishment of a thorough inspection program at all stages of service life (fabrication, assembly, storage, launch preparation and mission(s)).
Corrosion	g. In the design of structural members, the use of dissimilar metals, which when used together form electrical couples leading to galvanic corrosion of the member, should be controlled. When the use of dissimilar metals is unavoidable, protective, noncorrosive materials (coatings) to prevent galvanic corrosion action should be considered unless the metal couple has been satisfactorily demonstrated for the proposed application. Galvanic corrosion can readily lead to structural failures, especially in brackets, braces, etc.
Collision, Injury	h. If honeycomb materials are to be used as structural elements, procedures and instructions should be provided to prevent delamination of the skin from the honeycomb structure during fabrication. Delaminated honeycomb can create serious hazards to personnel since its structural strength has been degraded. Field repairs to delaminated honeycomb materials are very difficult and require controlled procedures to assure adequate repairs.
Corrosion	i. Definitions of environments to which the structural materials will be exposed should include but not be limited to the following:
	(1) Chemicals to be used in the cleaning, etching, and rinsing compounds.
	(2) Types of inspection fluids, marking inks, crayons, and lubricants to be used on the structural elements.
	(3) Types of machining fluids and testing fluids to be used.
	(4) Atmospheric use environments.
	(5) Service chemicals to be used during operations.
Corrosion	j. In the design of structural elements which are to be joined together by welding, the welding process selected should be compatible with the metallurgical properties of the material to avoid hydrogen embrittlement and possible structural failures.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.15 SUBSYSTEM STRUCTURES

ASSOCIATED HAZARD	GUIDELINES
	3.15.1.3 Structural Supports (continued)
Collision, Injury	a. Structural provisions, such as handrails, foot restraints, and attach points for tethering, should be considered in the design of payload structures for ease of transfer of equipment and crew aids during intravehicular or extravehicular activities.
Collision, Injury, Loss of Entry Capability	b. The design of payload structures should consider transportation and handling loads to which the payloads will be subjected such as: (1) Loading and unloading of the payload on or off the transportation vehicle. (2) Moving loads at the launch site by ground equipment. (3) Installation into and removal from the shuttle. Structural protection should be provided for all sensitive payload equipment whose failure during mission operations will create hazards to the crew.
Collision, Injury, Loss of Entry Capability	c. When considering the selection of cradles, shipping containers, and transportation vehicles, it should be assured that these devices are adequate and provide attenuation of transportation loads to values tolerated by the payload structures.
Injury	d. Mechanical support devices, such as brackets for movable control mechanisms, should be secured by a minimum of two fasteners to prevent rotation or displacement which could lead to mechanism failures.
Corrosion, Injury	e. Bolts, nuts, and similar structural fasteners should be selected for size, strength, and resistance to corrosive environments to avoid stress corrosion under operational conditions. Consideration should be given in the design for the maximum shear forces imposed on the fasteners in the event of a crashlanding. Selection of the proper fasteners to contain equipment during a crashlanding can prevent the creation of equipment projectiles.
Contamination	f. Proper hardness and heat treatment for structural fasteners should be specified as required for applications. Use of improper torque values or incorrectly selected fasteners may result in equipment failures.

PAYLOAD SAFETY GUIDELINES

SECTION NO. 3.15 SUBSYSTEM STRUCTURES

ASSOCIATED HAZARD	GUIDELINES
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